



BELL & HOWELL SCHOOLS

DeVRY INSTITUTE OF TECHNOLOGY



LESSON-LABORATORY SCHEDULE AND SELF-PROGRESS REPORT

This Lab and Lesson Schedule is a step-by-step study guide for the first 4 course units of your DeVry home-study program. A schedule for the remainder of the program will be sent when this portion has been completed. The schedule is a 'road map' to the best route through the text lessons, laboratory experiments, and unit exams which make up your home-study program. Study these lessons and experiments and submit the answer cards and unit examinations in the same order as they are listed in the schedule.

When you have completed one or two exams, mail the answer cards to us in one of our self-addressed envelopes. Be sure to PRINT your name, address, student number, and lesson number on each card you send in: please do not use an address label, or bend the card. Do not wait to complete more than two exam cards before mailing them in. If you hold the cards, you will delay mailing of new lessons and laboratory kits. We release new study material as soon as your answer cards indicate to us that you are ready for the next group of lessons and labs. If you send in your answer cards as soon as you complete them, you should receive additional study material well before you need it. Use this schedule to make sure you have the correct materials on hand before you begin to study. Each lesson and lab shipment has a code marked on its shipping carton. These codes are shown on the schedule in parentheses, e.g., (EL1-1).

We suggest that you keep this schedule for your personal records. By filling in the date each lesson and experiment is started and completed, you will have a permanent record of the pace at which you are progressing. Set a goal for yourself (such as the completion of one or two lessons per week). Check your record against your goal. When the time comes to review for a unit exam or your final exam, the record you have of time required to complete each lesson and of grades received will help you identify topics which were difficult for you that need special review.

NAME _____

STUDENT NUMBER K36739 1GW

STUDY GOAL _____



COURSE 104 - VOLUME I
INTRODUCTION TO ELECTRICITY AND ELECTRONICS (104SK)

SPECIAL INSTRUCTION Read "Making the Most of Home Study" (104SK)

- | | DATE
STARTED | DATE
COMPLETED | GRADE |
|---|-----------------|-------------------|-------|
| 1) 1001 Electricity and Electronics | | | |
| *SPECIAL INSTRUCTION* Read "Multimeter Instruction Manual" (EL1-1)* | | | |
| 2) 9500-1 Lab Exp.-Basic Circuits (EL1-1)* | | 5/8 | |
| 3) 1004 Conductors and Resistors | | | |
| 4) 9500-2 Lab Exp.-Resistance (EL1-1)* | | 5/8 | |
| 5) 1007 Voltage, Current and Resistance | | 5/8 | |
| 6) 9500-3 Lab Exp.-Ohm's Law (EL1-1)* | | | |
| 7) 1010 Series and Parallel Circuits | | 5/8 | |
| 8) 9500-4 Lab Exp.-Reference Points - Series and Parallel Circuits (EL1-1)* | | | |
| 9) 1013 Electric Power | | 5/8 | |
| 10) 9500-5 Lab Exp.-Power Calculations and Measurements (EL1-1)* | | | |
| 11) 1016 Using Electric Meters | | 5/9 | |
| 12) 9500-6 Lab Exp.-Loading Effects of Meters (EL1-1)* | | | |
| 13) 1019 Electrical Problem Solving | | 5/9 | |
| 14) 9500-7 Lab Exp.-Ohm's Law-Advanced Circuits (EL1-1)* | | 5/9 | |
| 15) 1022 DC Circuit Analysis | | | |
| 16) 9500-8 Lab Exp.-DC Circuit Analysis (EL1-1)* | | 5/9 | |
| 17) Unit Exam 104 | | | |

COURSE 125 - VOLUME 2
ACTIVE AND PASSIVE COMPONENTS (125)

SPECIAL INSTRUCTION Read "Soldering - Supplement 0208" (EL1-2) and "Introduction to Manual 9502" (EL1-2)

SPECIAL INSTRUCTION Submit Soldering Sample

SPECIAL INSTRUCTION Do Project 1 in Manual 9501 (EL1-2)

- | | | | |
|--|--|------|-----|
| 18) 1025 Semiconductors and Vacuum Diodes | | 11/8 | 100 |
| 19) 9502-1 Lab Exp.-Diodes (EL1-2)** | | X | |
| 20) 1028 Magnets and Electromagnets | | 11/8 | 100 |
| 21) 9502-2 Lab Exp.-Magnets and Electromagnets (EL1-2)** | | X | |
| 22) 1031 Alternating Current | | 11/8 | 100 |
| 23) 9502-3 Lab Exp.-Electromagnetic Induction (EL1-2)** | | X | |
| 24) 1034 Inductors and Transformers | | 11/8 | 100 |
| 25) 9502-4 Lab Exp.-Transformers (EL1-2)** | | X | |
| 26) 1037 Capacitors | | 11/8 | 100 |

*NOTE: Laboratory Manual 9500 is included in lesson shipment 104SK. All other laboratory manuals are contained in the corresponding laboratory shipment.

10,37
5
51,86

10,84
54,22
42
42

Dec 75

	DATE STARTED	DATE COMPLETED	GRADE
27) 9502-5 Lab Exp.-Capacitors (EL1-2)**		X ← paid up	
28) 1040 Electronic Power Supplies		11/8	100
29) 9502-6 Lab Exp.-Power Supplies (EL1-2)**		X	
SPECIAL INSTRUCTION Do Project 2 in Manual 9501 (EL1-2)			
30) 1043 Transistor Operation		11/8	100
31) 9504-1 Lab Exp.-Transistor Circuits Part I (EL1-3)**		X	
32) 1046 Transistor Characteristics		11/8	100
33) 9504-2 Lab Exp.-Transistor Circuits Part II (EL1-3)**		X	
34) 1049 Vacuum Tube Operations		11/8	100
35) 9504-3 Lab Exp.-Vacuum Tube Circuits Part I (EL1-3)**		X	
36) 1052 Vacuum Tube Characteristics		11/8	100
37) 9504-4 Lab Exp.-Vacuum Tube Circuits Part II (EL1-3)**		X	
38) Unit Exam 125		11/8 ← paid at →	

COURSE 242 - VOLUME 3

ALTERNATING CURRENT EFFECTS AND BASIC AMPLIFIER CIRCUITS (242)

39) 1055 Measuring Devices		X ← started quarter	X
40) 9504-5 Lab Exp.-Transistor Circuits Part III (EL1-3)**		X	X
41) 1058 Using Vectors		X	X
42) 9504-6 Lab Exp.-Vacuum Circuits Part III (EL1-3)**		X	80

SPECIAL INSTRUCTION Do Project 3 in Manual 9501 (EL1-2)

43) 1061 RLC Effects on AC		X	100
44) 9506-1 Lab Exp.-Investigating Capacitance and Inductance (EL1-4)		X	100
45) 1064 Frequency Effects on RLC Circuits		X	100
46) 9506-2 Lab Exp.-Resonance (EL1-4)		X	100
47) 1067 AC Power		X	100
48) 9506-3 Lab Exp.-Power in AC Circuits (EL1-4)		X	100
49) 1070 Networks		X	60
50) 9506-4 Lab Exp.-Time Constants (EL1-4)		X	100
51) 1073 Radio Frequency Effects		X	100
52) 9506-5 Lab Exp.-Time Constants Continued (EL1-4)		X	20
53) 1076 Vacuum Tube Low Frequency Amplifiers		X	100
54) 9506-6 Lab Exp.-Vacuum Tube Circuits Part IV (EL1-4)		X	100
55) 1079 Transistor Low Frequency Amplifiers		X	100
56) 9506-7 Lab Exp.-Transistor Circuits Part IV (EL1-4)		X	100
57) Unit Exam 242		X	

**NOTE: Due to postal regulations, the exam sheets for Laboratory Manuals 9502 and 9504 are found in the plastic bag marked "Third Class Mail Enclosure." We suggest that you interleave these exams after the corresponding experiment in the Manual as has already been done in Manual 9500 (104SK). (Manual 9504 is contained in the EL1-3 Shipment. Set aside the exams for this manual until Lesson 31.)

COURSE 252 - VOLUME 4
BASIC ELECTRONIC CIRCUIT APPLICATIONS (252)

58)	1082	Transducers
59)	9508-1	Lab Exp.-Transducers (EL1-5)
60)	1085	Electronic Systems
61)	9508-2	Lab Exp.-Complete Electronic Systems (EL1-5)
62)	1088	Vacuum Tube High Frequency Amplifiers
63)	9508-3	Lab Exp.-Vacuum Tube Circuits Part V (EL1-5)
64)	1091	Transistor Push-Pull and High Frequency Amplifiers
65)	9508-4	Lab Exp.-Transistor Circuits Part V (EL1-5)
66)	1094	Vacuum Tube Oscillators
67)	9508-5	Lab Exp.-Vacuum Tube Oscillators (EL1-5)
68)	1097	Transistor Oscillators
69)	9508-6	Lab Exp.-Transistor Oscillators (EL1-5)
70)	1100	Field Effect Transistors
71)	9510-1	Lab Exp.-FET's (EL1-6)
72)	1103	Semiconductor Control Devices
73)	9510-2	Lab Exp.-Unijunction Transistors (EL1-6)
74)	1106	Motors and Generators
75)	9510-3	Lab Exp.-SCR's (EL1-6)
76)	1109	Printed Circuit Techniques
77)	9510-4	Lab Exp.-Transistor Circuits Part VI (EL1-6)
78)	1112	Integrated Circuits
79)	9510-5	Lab Exp.-Operational Amplifier (EL1-6)
80)	1115	Electromechanical Devices
81)	9510-6	Lab Exp.-Relays (EL1-6)
82)	Unit Exam 252	

DATE STARTED	DATE COMPLETED	GRADE
	X	100
	X	100
	X	80
	X	100
	X	100
	X	100
	X	100
	X	90
	X	80
	X	100
	X	100
	X	100
	X	100
	X	100
	X	100
	X	90
	X	100
	X	100
	X	100
	X	70
	X	100
	X	85

sent in 19 Jan
sent in Feb

2nd quarter

62 errors

24

LESSON-LABORATORY SCHEDULE AND SELF-PROGRESS REPORT

This Lab and Lesson Schedule is a step-by-step study guide for the second part of your DeVry home-study program. The schedule is a 'road map' to the best route through the text lessons, laboratory experiments, and unit exams which make up your home-study program. Study these lessons and experiments and submit the answer cards and unit examinations in the same order as they are listed in the schedule.

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NAME _____

STUDENT NUMBER _____

STUDY GOAL _____



COURSE 74 - VOLUME 5

ELECTRONIC CIRCUITS AND SYSTEMS AND
ELECTRONIC APPLICATIONS (74)

	DATE STARTED	^{sent in} DATE COMPLETED	GRADE
7405	Linear Integrated Circuits	6 April	100
7410	Regulated Power Supplies	6 April	80
7415	Photoelectric Principles	6 April	100
7420	Electronic Meters	6 April	100
7425	Cathode Ray Tubes and Oscilloscopes	6 April	100
7430	Electronic Display Devices	6 April	100
9550-1	Digital Multimeter - Part I (ICM-1)	13 April	80
7435	Motors and Generators	6 April	100
7440	Power Transfer and Impedance Matching	6 April	100
7445	Modulation and Demodulation	13 April	100
7450	Communications Systems	13 April	100
Unit Exam 74		13 April	96

12

COURSE 52 - VOLUME 6

LOGIC CIRCUITS (52)

5205	Concepts of Switching Logic	7 July	100
9550-2	Digital Multimeter - Part II (ICM-2)	13 Sept	100
5210	Switching Characteristics	7 July	100
5215	Diode Logic Circuits	7 July	100
5220	Active Switching Circuits	7 July	100
5225	Basic Combinational Logic	23 Aug	100
5230	Coding and Decoding Circuits	23 Aug	100
5235	Basic Arithmetic Circuits	23 Aug	100
9560-1	Solid-State Oscilloscope - Part I (DCS-1)	8 Nov	
5240	Digital Integrated Circuits	23 Aug	90
5245	Register and Counter Circuits	23 Aug	100
5250	Data Storage Circuits and Devices	23 Aug	100
Unit Exam 52		23 Aug	88

23

COURSE 75 - VOLUME 7

RADIO AND SOUND SERVICING (75)

7505	Servicing Equipment	23 Aug	100
7510	Troubleshooting Techniques	7 Sept	100
7515	Broadcast Radio Servicing	7 Sept	100
9560-2	Solid-State Oscilloscope - Part II (DCS-2)	8 Nov	
7520	Servicing Automobile Receivers	7 Sept	90
7525	Servicing Intercoms and PA Systems	7 Sept	100

		DATE STARTED	DATE COMPLETED	GRADE
7530	Hi-Fi Stereo Systems		7 Sept	90
7535	Troubleshooting High-Fidelity Amplifiers		7 Sept	90
7540	Servicing Record Changers and Turntables		13 Sept	100
7545	Tape Recorder Repair		13 Sept	100
9560-3	Solid State Oscilloscope - Part III (DCS-3)		8 Nov	
7550	Servicing AM-FM/Stereo Receivers		13 Sept	90
Unit Exam 75			13 Sept	88

COURSE 76 - VOLUME 8

TELEVISION PRINCIPLES - PART I (76)

7605	Television Principles		8 Nov	90	
7610	Television System Requirements		8 Nov	90	
7615	Tuner Circuits		13 Dec	100	
7620	VHF Tuners		13 DEC	100	
7625	Video I-F Section		13 Jan	100	
9521-1	Advanced Lab (EL3-1)		4 Feb	90	
7630	Video Amplifiers		13 Jan	100	
7635	Monochrome Picture Tubes		13 Jan	100	
7640	Sound Channels		13 Jan	90	
7645	Sync Signals		13 Jan	90	
7650	Sync Circuits and DC Restorers		13 Jan	100	
Unit Exam 76			13 Jan	96	

97 lesson

31 Dec 77

115
assess

49

164

COURSE 77 - VOLUME 9

TELEVISION PRINCIPLES - PART II (77)

7705	Sweep Oscillators		13 Jan	100	
9521-2	Advanced Lab (EL3-1)		4 Feb	100	
7710	Sweep Amplifiers		13 Jan	70	
7715	High-Voltage Supplies		13 Jan	90	
7720	Horizontal AFC Circuits		13 Jan	90	
7725	Automatic Gain Control		13 Jan	90	
7730	Low-Voltage Supplies		13 Jan	100	
7735	UHF Tuners		13 Jan	100	
9521-1	Advanced Lab (EL3-2)		4 Feb	90	
7740	Antennas		13 Jan	90	
7745	Transmission Lines		13 Jan	100	
7750	Monochrome Television Receivers		13 Jan	100	
Unit Exam 77			13 Jan	80	

COURSE 78 - VOLUME 10

TELEVISION SERVICING (78)

		DATE STARTED	DATE COMPLETED	GRADE
7805	Control Adjustments		17 Jan	90
9360	TV Experiments I (GRD 20A - GRD 21)		22 Feb	90
7810	Initial Investigation and Adjustment		17 Jan	100
7815	Test Procedures		17 Jan	90
7820	Horizontal Deflection Systems		17 Jan	100
7825	Vertical Deflection Systems		17 Jan	100
7830	Monochrome Receiver Alignment		17 Jan	90
9363	TV Experiments II (GRD 22)		22 Feb	100
7835	Parts Replacement		17 Jan	100
7840	Reception Problems		17 Jan	100
7845	Time Savers		17 Jan	100
7850	Servicing in Home and Shop		17 Jan	100
Unit Exam	X 831		31 Jan	92

COURSE 79 - VOLUME 11

COLOR TELEVISION (79)

7905	Color		17 Jan	90
9366	TV Experiments III (GRD 23)		3 Mar	
7910	Color TV Picture Tubes		17 Jan	100
7915	Color Television Signals		17 Jan	100
7920	Color Television Receivers		17 Jan	100
7925	Color Signal Amplifiers		17 Jan	100
7930	Color Sync Circuits		17 Jan	100
9369	TV Experiments IV (GRD 24)		3 Mar	
7935	Color Tube Circuits and Assemblies		17 Jan	100
7940	Color TV Receiver Installation		17 Jan	100
7945	Monochrome Picture Problems		17 Jan	100
7950	Color Picture Problems		17 Jan	100
7955	Color TV Alignment		17 Jan	100
9372	TV Experiments V (GRD 25 - TV-9M)		3 Mar	100
Unit Exam 79			4 Feb	92
Final Exam				

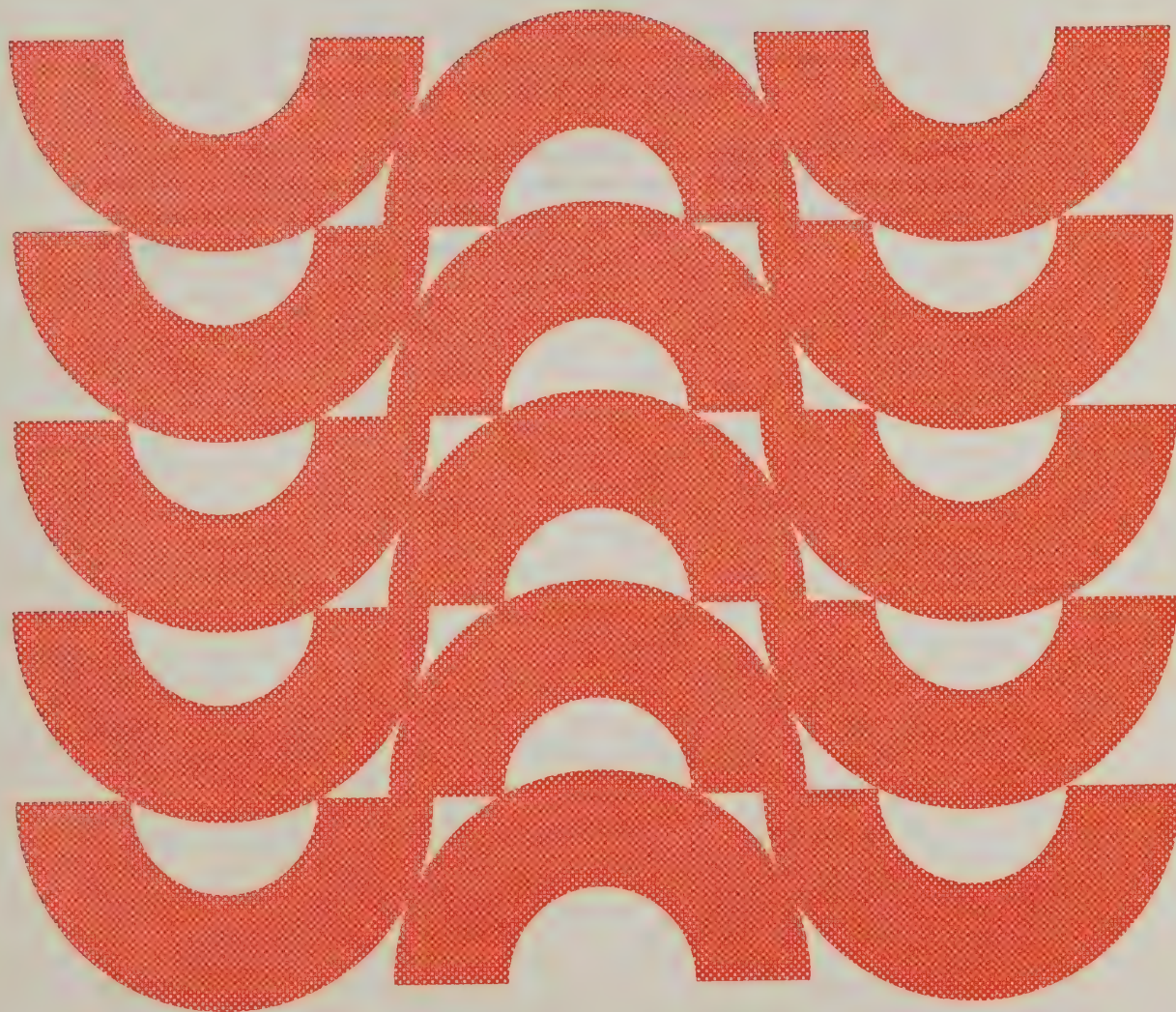


BELL & HOWELL SCHOOLS

DEVRY INSTITUTE OF TECHNOLOGY

**INTRODUCTION TO ELECTRICITY
AND ELECTRONICS**

COURSE 104



IMPORTANT NOTICE

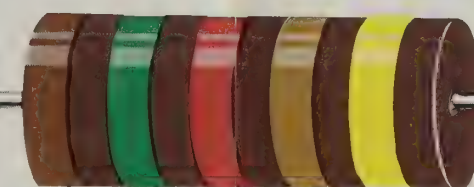
This packet of lesson material contains several features which we would like to call out by placing them at the front of the material. The first of these is the large resistor color code chart. You will find it just below this sheet. It is printed to agree with the industrial and military colors. This chart lists the standard resistor values and should be a valuable reference tool for you. Because of the standard variations in making resistors, the colors on the resistors you use may vary from the standard colors. If you wish, the chart can be inserted into your lesson material. The place to put it would be between Pages 16 and 17 of Lesson 1004. This lesson has the heading "Conductors and Resistors" at the top of each page of text.

The second sheet below this Important Notice is labeled Q3 on the top of one side and Q3A on the top of the other side. Side Q3A shows color bands on resistors. This sheet should be inserted in Lesson 1004—Conductors and Resistors—between Pages 20 and 21.

COLOR CODE FOR STANDARD VALUE FIXED COMPOSITION RESISTORS

First Band	Second Band	Third Band	Resistance Ω	First Band	Second Band	Third Band	Resistance Ω	First Band	Second Band	Third Band	Resistance Ω	First Band	Second Band	Third Band	Resistance Ω
Brown	Black	Black Brown Red Orange Yellow Green Blue	10 100 1000 10000 0.1 Meg. 1.0 Meg. 10.0 Meg.	Red	Black	Black Brown Red Orange Yellow Green Blue	20 200 2000 20000 0.20 Meg. 2.0 Meg. 20.0 Meg.	Orange	Orange	Gold Black Brown Red Orange Yellow Green	3.3 33 330 3300 33000 0.33 Meg. 3.3 Meg.	Green	Brown	Gold Black Brown Red Orange Yellow Green	5.1 51 510 5100 51000 0.51 Meg. 5.1 Meg.
	Brown	Black Brown Red Orange Yellow Green Blue	11 110 1100 11000 0.11 Meg. 1.1 Meg. 11.0 Meg.		Red	Black Brown Red Orange Yellow Green Blue	22 220 2200 22000 0.22 Meg. 2.2 Meg. 22.0 Meg.		Blue	Gold Black Brown Red Orange Yellow Green	3.6 36 360 3600 36000 0.36 Meg. 3.6 Meg.		Blue	Gold Black Brown Red Orange Yellow Green	5.6 56 560 5600 56000 0.56 Meg. 5.6 Meg.
	Red	Black Brown Red Orange Yellow Green Blue	12 120 1200 12000 0.12 Meg. 1.2 Meg. 12.0 Meg.		Yellow	Black Brown Red Orange Yellow Green	24 240 2400 24000 0.24 Meg. 2.4 Meg.		White	Gold Black Brown Red Orange Yellow Green	3.9 39 390 3900 39000 0.39 Meg. 3.9 Meg.		Red	Gold Black Brown Red Orange Yellow Green	6.2 62 620 6200 62000 0.62 Meg. 6.2 Meg.
	Orange	Black Brown Red Orange Yellow Green Blue	13 130 1300 13000 0.13 Meg. 1.3 Meg. 13.0 Meg.		Violet	Gold Black Brown Red Orange Yellow Green	2.7 27 270 2700 27000 0.27 Meg. 2.7 Meg.		Orange	Gold Black Brown Red Orange Yellow Green	4.3 43 430 4300 43000 0.43 Meg. 4.3 Meg.		Gray	Gold Black Brown Red Orange Yellow Green	6.8 68 680 6800 68000 0.68 Meg. 6.8 Meg.
	Green	Black Brown Red Orange Yellow Green Blue	15 150 1500 15000 0.15 Meg. 1.5 Meg. 15.0 Meg.		Orange	Gold Black Brown Red Orange Yellow Green	3.0 30 300 3000 30000 0.30 Meg. 3.0 Meg.		Violet	Gold Black Brown Red Orange Yellow Green	4.7 47 470 4700 47000 0.47 Meg. 4.7 Meg.		Violet	Gold Black Brown Red Orange Yellow Green	7.5 75 750 7500 75000 0.75 Meg. 7.5 Meg.
	Blue	Black Brown Red Orange Yellow Green Blue	16 160 1600 16000 0.16 Meg. 1.6 Meg. 16.0 Meg.		Orange	Black		Yellow		Violet		Gray	Red	Gold Black Brown Red Orange Yellow Green	8.2 82 820 8200 82000 0.82 Meg. 8.2 Meg.
	Gray	Black Brown Red Orange Yellow Green Blue	18 180 1800 18000 0.18 Meg. 1.8 Meg. 18.0 Meg.											Gold Black Brown Red Orange Yellow Green	9.1 91 910 9100 91000 0.91 Meg. 9.1 Meg.

Standard Color Code



First Band 1st Digit		Second Band 2nd Digit		Third Band Multiplier		Fourth Band Resistance Tolerance		Fifth Band Reliability Level (Percent Per 1,000 Hours)	
Color	Digit	Color	Digit	Color	Multiplier	Color	Tolerance	Color	Level
Black	0	Black	0	Black	1	Silver	$\pm 10\%$	Brown	M = 1.0%
Brown	1	Brown	1	Brown	10	Gold	$\pm 5\%$	Red	P = 0.1%
Red	2	Red	2	Red	100	*No Band	$\pm 20\%$	Orange	R = 0.01%
Orange	3	Orange	3	Orange	1,000			Yellow	S = 0.001%
Yellow	4	Yellow	4	Yellow	10,000			*MIL-R-39008 Resistors Only	
Green	5	Green	5	Green	100,000				
Blue	6	Blue	6	Blue	1,000,000				
Violet	7	Violet	7	Silver	0.01				
Gray	8	Gray	8	Gold	0.1				
White	9	White	9						



ALLEN-BRADLEY

ELECTRONICS DIVISION
MILWAUKEE, WISCONSIN

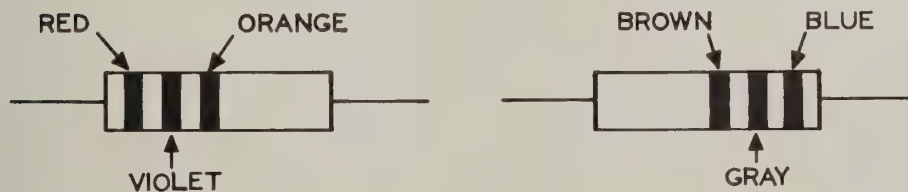
The following Practice Exercise questions cover the subjects which you have just studied. They are:

RESISTOR RATINGS

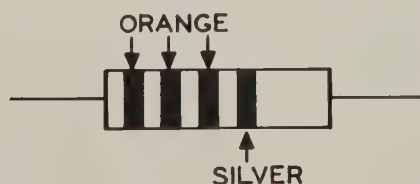
RESISTOR COLOR CODE

RESISTANCE DESIGNATIONS

25. What factors determine the resistance of a resistor?
26. What are three of the most important ratings of a resistor?
27. You have two carbon resistors that are $1/4''$ in diameter. One is $1/2''$ long and the other is $1''$ long. Which one can probably dissipate the most heat?
28. What is the reason for color coding resistors used in electronic equipment?
29. What is the value of a resistor with a green 1st band, a blue 2nd band and a red 3rd band?
30. What is the value of a resistor with a yellow 1st band, violet 2nd band, and orange 3rd band?
31. What is the resistance of a resistor which has three orange bands?
32. What are the resistance values of the two resistors in the drawings below?



33. Between what two values (maximum and minimum) should the actual resistance be of the resistor shown below?



34. Use the chart below to enter the values of the resistors shown on this page as indicated by the three color bands on the body of the resistors. First list the resistor values in ohms and then convert each value to more convenient units, kilohms or megohms, if the value is 1000 ohms or more. The fourth band on the resistors is not present, and therefore all resistors have a 20% tolerance. Remember to start reading the value of a resistor with the band closest to one end of the resistor.

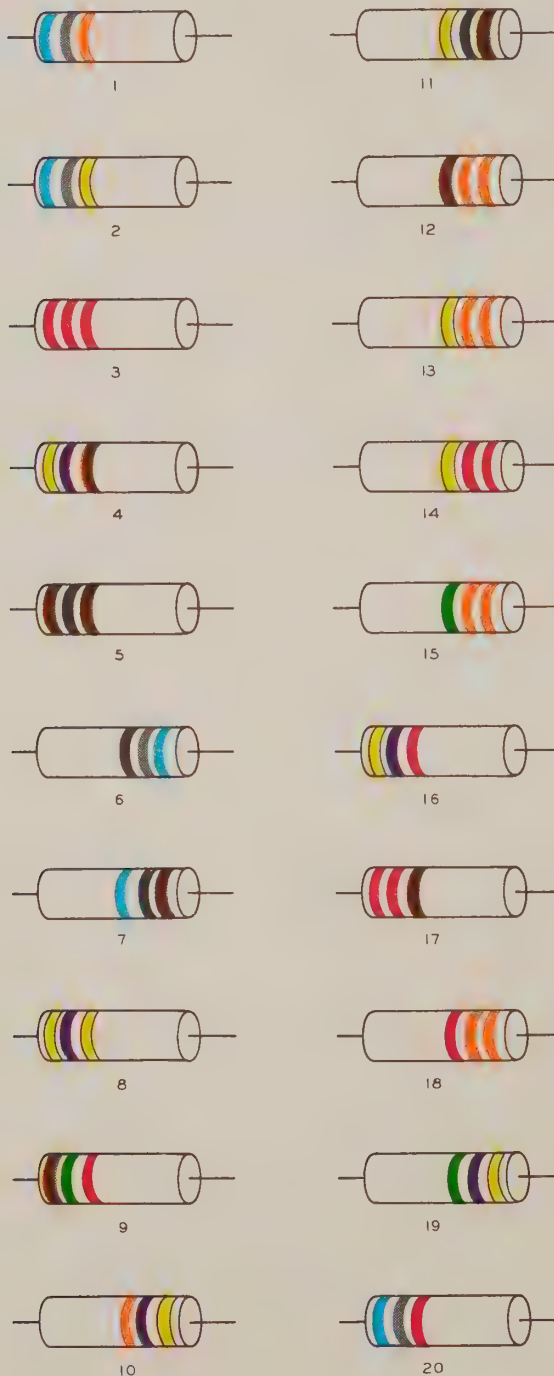


Diagram Number	Value of Resistor	
	In Ohms	in $k\Omega$'s or Meg Ω 's
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

INTRODUCTION TO ELECTRICITY AND ELECTRONICS

CONTENTS

ELECTRICITY AND ELECTRONICS	Lesson 1001
CONDUCTORS AND RESISTORS	Lesson 1004
VOLTAGE, CURRENT AND RESISTANCE	Lesson 1007
SERIES AND PARALLEL CIRCUITS	Lesson 1010
ELECTRIC POWER	Lesson 1013
USING ELECTRIC METERS	Lesson 1016
ELECTRICAL PROBLEM SOLVING	Lesson 1019
DC CIRCUIT ANALYSIS	Lesson 1022
UNIT EXAMINATION	Course 104

THE UNIVERSITY OF CHICAGO
DEPARTMENT OF CHEMISTRY
RESEARCH REPORT NO. 1000

1. Introduction
2. Experimental
3. Results
4. Discussion
5. Conclusion
6. References
7. Appendix
8. Acknowledgments
9. Author's Address
10. Summary

11. Index
12. Glossary
13. Bibliography
14. Figures
15. Tables
16. Appendix
17. Acknowledgments
18. Author's Address
19. Summary
20. Index

ELECTRICITY AND ELECTRONICS

1001

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Electronics makes possible computers such as this. A complete digital computer system consists of a number of individual units. The units work together to process information quickly and accurately.

Courtesy G. E. Information Systems Div.

CONTENTS

Opportunities in Electronics	Page 4
Energy	Page 4
Forms of Energy	Page 5
Electricity and Electronics	Page 5
Structure of Matter	Page 6
Electricity	Page 8
Current	Page 10
Source, Load and Circuit	Page 11
Direct and Alternating Current	Page 12
Symbols	Page 13
Schematic Diagrams	Page 14

Think like a man of action and act like a man of thought.
—Henry Bergson

ELECTRICITY AND ELECTRONICS

OPPORTUNITIES IN ELECTRONICS

Where will you fit into the existing field of Electronics? Will you be the “key” person who keeps a complex electronically controlled operation going? Will you work hand in hand with engineers to develop new instruments and control systems? Will you be the one maintaining thousands of radio, TV and music systems providing entertainment to their owners? There is no limit to the opportunities open to you!

No single field has had a greater impact on our way of life than Electronics. Our lives are regulated by Electronics. The products we buy are manufactured with the aid of Electronics. Electronics controls our travel and makes it safer. We are living in the “Age of Electronics.”

As an Electronics Technician, you enjoy the prestige of a “specialist.” You will find opportunities in radio, television, hi-fi/stereo, aeronautics, nuclear, public utilities, medicine and health, aerospace technology, chemical and petroleum processing, glass and ceramics, pulp and paper, rubber and plastics and almost anywhere you turn. There is a rewarding, exciting place for YOU in one of these areas.

With this lesson you are taking the first giant step toward your goal in an exciting and growing technical area. Your educational program has been designed to give you the all-important **PRACTICAL EXPERIENCE** necessary for success in this fast-moving field. You will be amazed at how quickly you will learn. Remember, there is no subject too difficult for you—just take one step at a time. Good luck!

ENERGY

The first building block in the study of electronics is an understanding of **ENERGY**. Energy is the “ability to do work.” To illustrate the idea of energy, consider the action of a dam. A heavy wall holds back a large reservoir of water. The water exerts a force against the dam and, if released, the water will fall. The water pushing against the dam has **POTENTIAL ENERGY** or energy at rest.

Now suppose the water is released through the pipes carrying it to the turbines of a dam power station. The turbine blades rotate as the water pushes past them. The rotating turbine blades turn a shaft that turns the gen-

erators, producing electricity. The water is in motion flowing through the turbines and the water has **KINETIC ENERGY** or energy of motion.

The potential energy of the water becomes kinetic energy as it goes into motion and drives the turbines. The water is doing **WORK** as it drives the turbines. Therefore, an energy conversion has taken place. Potential energy has been converted into kinetic energy to do work.

FORMS OF ENERGY

Energy has many forms—mechanical, electrical, chemical, nuclear, heat and light, to name a few. The ability to convert from one form of energy to another has made possible our great scientific progress. To illustrate the idea of energy conversion, consider the automobile, an energy conversion device. The chemical energy of gasoline and air is converted into heat energy when ignited. The heat energy is then converted into mechanical energy to move the automobile.

Some of the mechanical energy produced by the automobile engine is used to operate an electric generator. This generator converts mechanical energy into electric energy. The headlights in turn convert the electric energy into light energy. Multiple conversion of energy occurs in almost everything we use.

The form of energy we are concerned with in the study of Electronics is electric energy. Electronics involves both the use of electric energy and its conversion into other forms. A television receiver uses electric energy and converts some of it into sound and light energy.

ELECTRICITY AND ELECTRONICS

The term **ELECTRICITY** is often used to describe electric energy in either its kinetic or potential form. Usable energy must be controlled and put to work. Thus, the study of **ELECTRONICS** is the study of the control and use of electricity or electric energy.

The question is often asked, just what is electricity? Electricity is actually an invisible force. We detect its presence by observing the effects it produces. A lightning stroke is probably one of the most vivid examples of the presence of electricity. Actually it is an example of an “uncontrolled use”

of electricity. Conversely, an electric lamp is an example of a device which makes controlled use of electricity.

Although electricity is invisible, we know what it is. To examine the nature of electricity, we must examine the way in which all materials are formed.

STRUCTURE OF MATTER

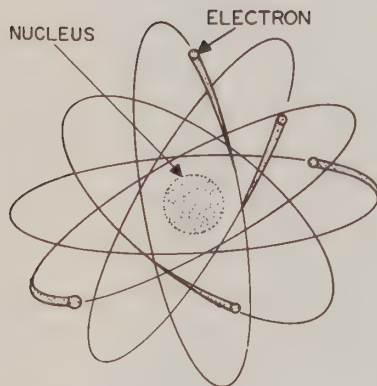


Figure
1

Thousands of years of scientific progress have given us a pretty good picture of the structure of matter. All materials are made up of tiny particles which we call **MOLECULES**. Molecules are so small that they are invisible to the unaided eye. In fact, millions of molecules can be found on the head of a pin. Also, we know that molecules, in turn, are made up of even smaller particles, each of which is called an **ATOM**.

Atoms, in turn, can be broken down into even smaller particles. These smaller particles are actually the building blocks of all matter. Figure 1 shows the basic arrangement of an atom. The arrangement is so similar to our own solar system that it is common to think of an atom as a miniature solar system. Compared to the sun in our solar system, the **NUCLEUS** is located in the center of the atom. A tiny particle called an **ELECTRON** rotates in orbit around the nucleus just as a planet rotates around the sun.

The electrons are prevented from being pulled into the nucleus by the force of their momentum. They are prevented from flying off into space by an attraction between the electron and the nucleus. This attraction is the basis for electricity and is related to the **CHARGE** on the electron and the nucleus. The electron is said to have a "negative" charge and the nucleus is said to have a "positive" charge.

Electrons are the same, regardless of the type of material in which they appear. All electrons have the same amount of negative charge and their weights are identical. Each type of atom differs from all other types of atoms in the number of electrons it contains and in the structure of the nucleus. For example, an atom of gold contains 79 electrons while an atom of iron contains 26 electrons.

There are over 100 types of materials which can be broken down into atoms without changing their characteristics. These materials are called elementary substances or simply **ELEMENTS**. Examples of elements are pure iron, pure copper and others. A pure copper or iron atom has the same char-

acteristics as a bar made up of pure copper or iron containing millions of atoms. All the thousands of other materials are combinations or mixtures of the atoms of the basic elements. For example, each molecule of pure water is made up of two atoms of hydrogen and one atom of oxygen.

If it were possible to pick out two electrons for experimental purposes, we would find that they resist any attempt to bring them together. If we let them go, they would fly apart! The same action would result if we tried to bring together a couple of nuclei (plural of nucleus). In both cases, the particles with like charges would repel each other.

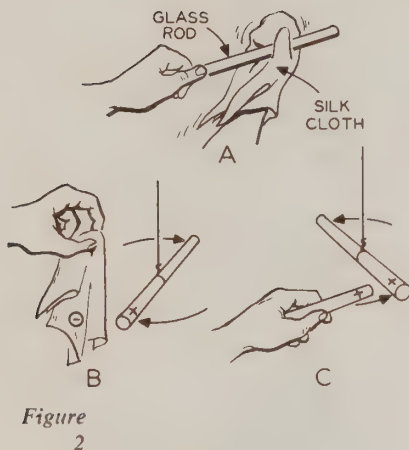
Repeating the experiment with an electron and a nucleus would produce different results. The two particles with unlike charges would fly together if we let them go. This action illustrates one of the basic laws of electricity and electronics:

**LIKE CHARGES REPEL;
UNLIKE CHARGES ATTRACT.**

In an atom, the negative charge of the electrons is balanced by the positive charge of the nucleus. As a result, an atom itself has no charge and we say it is neutral.

The atoms of a material like copper have a number of electrons in orbits around the nucleus. These electrons are in orbits at different distances from the nucleus. In general, the farther away from the nucleus the electrons are, the smaller is the force that bonds them to the atom. Actually, the electrons in the outer orbits of the copper atom are able to drift from one atom to another. These electrons are called **FREE ELECTRONS**. The free electrons drift from one atom to another in a haphazard manner, never all going in one direction at the same time. Even though the electrons are drifting about, the material remains with an overall neutral charge.

By applying external energy, it is possible to remove or add electrons to atoms. The addition of an electron gives the atom a negative charge while the removal of an electron produces an atom with a positive charge. To alter the charge of the nucleus requires a tremendous expenditure of energy and this action is the basis for nuclear power. An atom that has gained or lost an electron is called an **ION**.



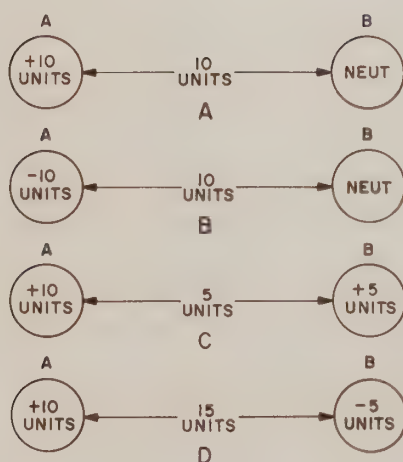
The ability to make an object take on a positive or negative charge together with the availability of free electrons in certain materials permits us to generate the invisible force called electricity.

ELECTRICITY

An experiment demonstrating the basic principles of electricity is shown in Figure 2. When a glass rod is rubbed with a silk cloth as in Figure 2A, millions of electrons are carried away from the glass rod and accumulated on the silk cloth. This leaves the glass rod with a deficiency of electrons or a positive charge, and the silk cloth with an excess of electrons or a negative charge. The charges are indicated in Figure 2B by the negative symbol (—) on the cloth and the positive symbol (+) on the rod.

If the glass rod is suspended and brought close to the silk cloth as in Figure 2B, they will be attracted (**UNLIKE CHARGES ATTRACT**). If another glass rod is rubbed to produce a positive charge, it will repel the other glass rod as shown in Figure 2C.

To summarize the action, charges are set up by a transfer of electrons from one object to another. Electrons are neither created nor destroyed but moved from one place to another. When electrons leave one point to produce a positive charge, they show up at another point to produce a negative charge. The charges produced by the transfer of electrons from one object to another are called **STATIC ELECTRICITY**.



The ability of a charged body to attract or repel another charged body is called its **POTENTIAL**. A body with a positive charge has a “positive potential” while a negatively charged body has a “negative potential.” The amount of work that can be done depends upon the difference of potential between two charged bodies. This is like the water held back by the dam. The farther it falls, the more energy it develops and the more work it can do. The potential energy of charged bodies depends upon the amount of charge.

To measure the potential or charge of a body we need a reference. Potential is often considered with respect to a body with no charge or what is called an electrically neutral body. The potential of a body with respect to a reference is called the **POTENTIAL DIFFERENCE**.

Figure 3 illustrates the concept of potential difference. In Figure 3A, body A has a charge of +10 units and body B has a neutral charge. Thus,

The following Practice Exercise questions cover the subjects which you have just studied. They are:

ENERGY

FORMS OF ENERGY

ELECTRICITY AND ELECTRONICS

STRUCTURE OF MATTER

1. When you hold an object off the ground, the object will have _____ energy.
2. An automobile in motion has _____ energy.
3. The use of energy is referred to as _____.
4. Electric generators convert _____ energy into _____ energy.
5. A television receiver is an example of the _____ use of electricity.
6. A small particle that is composed of atoms is the (a) electron, (b) molecule, (c) nucleus.
7. The small particles which revolve around the nucleus in an atom are called (a) molecules, (b) neutrons, (c) electrons.
8. An electron has a _____ charge and the nucleus has a _____ charge.
9. A material which can be divided down into atoms without losing its characteristics is called an _____.

- 10. What is the basic law of electricity and electronics?**
- 11. What are free electrons?**
- 12. An atom that has a negative charge is called an ion. True or False?**

the difference in potential is 10 units. In Figure 3B, body A has a charge of -10 units and body B is neutral. Thus, the difference in potential is 10 units. The arrangements of Figures 3A and 3B both have the same difference in potential. However, in Figure 3A, body A is $(+)$ and in Figure 3B body A is $(-)$. Thus, in Figure 3A, body A has a difference of potential of $+10$ units with respect to the neutral reference. In Figure 3B, body A has a difference in potential of -10 units with respect to the neutral reference.

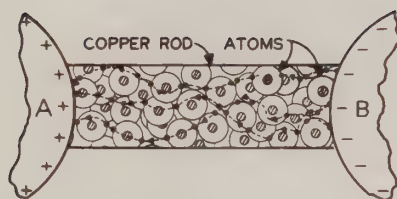
Figure 3C illustrates another situation. Here body A has a charge of $+10$ units while body B has a charge of $+5$ units. The difference in potential between the two bodies is 5 units. Although both bodies have the same polarity (they are both positive), we can establish a polarity for one with respect to the other. Since the charge on body A is **MORE POSITIVE** than on body B, we can say that body A has a difference in potential of $+5$ units with respect to body B. However, since the charge on body B is **LESS POSITIVE** than the charge on body A, we can also say that body B has a difference in potential of -5 units with respect to A. Both bodies, though, have a positive charge with respect to a neutral body. Thus, when dealing with two charged bodies, the polarity depends upon the reference.

Figure 3D illustrates the difference in potential between two oppositely charged bodies. This situation is much like comparing two readings on a thermometer. Zero degrees is the reference on a thermometer. To compare a temperature above zero with a temperature below zero we add the amount one is above zero to the amount the other is below zero. For example, assume we wish to compare a reading of 20° above zero with a reading of 10° below zero. The reading of 20° above zero is 30° above the reading of 10° below zero. In Figure 3D, body A has a charge of $+10$ units and body B has a charge of -5 units. Thus, body A has a difference in potential of 15 units with respect to body B. Since body A has a $+$ charge with respect to body B, body A has a difference in potential of $+15$ units with respect to body B. We can also say that body B has a difference in potential of -15 units with respect to body A.

In electricity and electronics we use the term **VOLTAGE** in place of difference in potential. The term voltage is used to describe the electric “pressure” or force that exists between charged bodies. The standard unit of measure to express a difference in potential or voltage is the **VOLT**.

A charged body is thus electricity in the form of potential energy. One way of doing work with this potential is to convert it into kinetic energy or put it into motion!

CURRENT

Figure
4

Assume that we have two bodies of opposite charge with a difference in potential or voltage existing between them. Also assume that we connect a copper rod between them as shown in Figure 4. Copper is a material with many free electrons. A material with many free electrons is called a **CONDUCTOR**. Since body A has a positive potential, it attracts the free electrons in the conductor toward it. As free electrons are drawn from the copper rod to body A, the rod takes on a positive charge as it is losing electrons. As this occurs, the excess electrons on body B flow into the conductor to take the place of those flowing to the positively charged body A. This flow of free electrons is called a **CURRENT**. This current continues as long as a difference in potential exists between the two bodies.

The potential energy of a charged body has now been converted into kinetic energy, a flow of electrons. We now have electricity in motion and it can be put to work. Electricity and electronics involve the study of how we produce and control the flow of electrons, as well as how we put the current to work.

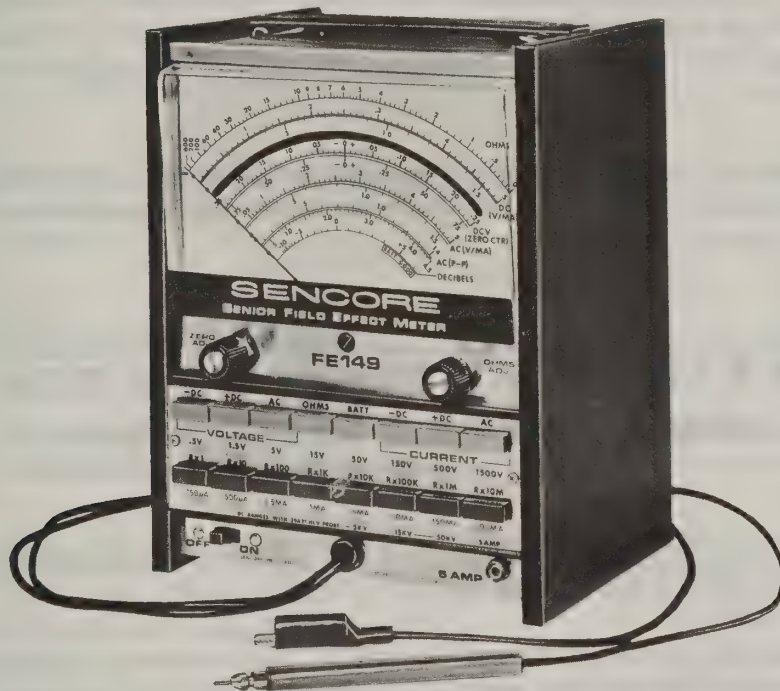
The movement of electrons in the copper rod shown in Figure 4 is somewhat random. However, the overall movement is from the negatively charged body to the positively charged body.

Electric current is measured by the number of electrons that pass by a point in a given period of time. The basic unit of measure is the **AMPERE**. An ampere is approximately 6,000,000,000,000,000 electrons moving past a point in one second. For convenience this quantity of electrons is called a **COULOMB**. Thus, an ampere is one coulomb of electrons per second.

In many cases the ampere is too large a unit. To avoid expressing the current as a fraction of an ampere, we use smaller units. One smaller unit is the **MILLIAMPERE** which is equal to one-thousandth of an ampere. Saying it another way, there are one thousand milliamperes in an ampere. The abbreviation for milliampere is mA.

Since current may be expressed in either unit, you should be able to convert from one to another. For example, 2 amperes equals 2000 milliamperes (multiply amperes by 1000 to obtain milliamperes). To change milliamperes into amperes, divide by 1000. Thus, 250 milliamperes equals .25 ampere.

A unit even smaller than the milliampere is the **MICROAMPERE**. A microampere, abbreviated μA , is one-millionth of an ampere. This means that there are one million microamperes in an ampere. To change from amperes to microamperes, simply multiply by 1,000,000. Thus, 5 amperes equals 5,000,000 microamperes. To change from microamperes to amperes, divide by 1,000,000. Thus, 500,000 microamperes equals .5 ampere.



Instruments can be used to measure the actual voltage and current values in a circuit.

Courtesy Sencore, Inc.

SOURCE, LOAD AND CIRCUIT

Electricity, as described earlier, is the force associated with an electric charge. To be of use, we must put this force and the flow of electrons it produces to work. That is, we must control the flow of electrons. To show how this is accomplished, let's examine a simple electrical system, that of a flashlight.

Every electrical system has three basic parts no matter how complex it is—**SOURCE**, **LOAD** and **CIRCUIT**. The source is a device which develops a

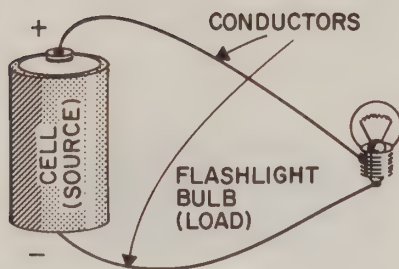


Figure 5

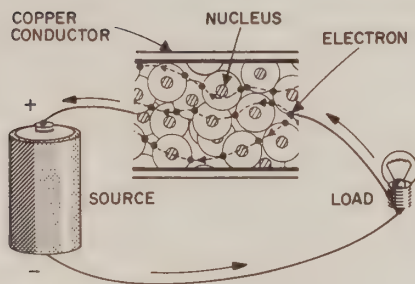


Figure 6

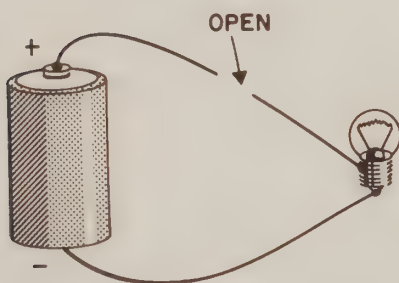


Figure 7

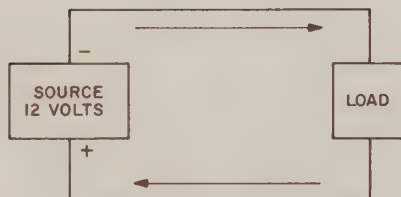


Figure 8

difference in potential or voltage. The load is a device which performs some function when an electric current flows through it. The circuit is composed of conductors which connect the source to the load. The difference in potential developed by the source causes the free electrons in the conductors to move through the load.

Figure 5 shows a pictorial diagram of the electrical system of a flashlight. The source develops a difference in potential. In the case of a flashlight cell, this is done through chemical action. The difference in potential, or voltage, causes the free electrons in the conductors to flow as illustrated in Figure 6.

Electrons are repelled at the (—) terminal and attracted to the (+) terminal of the source. This sets up a flow of electrons in the circuit from (—) to (+) as shown.

IN A CIRCUIT, ELECTRONS ALWAYS FLOW FROM NEGATIVE (—) TO POSITIVE (+).

This flow of electrons through the lamp heats up the wire in the lamp to the point where this section of wire gives off light.

Electrons flow in the system until the cell no longer produces a difference in potential. Electron flow also stops if the path is broken, as shown in Figure 7. There must be a **COMPLETE CIRCUIT** for electron flow. This fact is the basis for one of the simplest of control devices, a “switch.” The switch is a device which opens and closes the path for electrons, thus controlling their flow. When the switch on a flashlight is closed, electrons flow through the lamp, causing it to give off light.

The source in the electrical system provides a force or “electric pressure” which causes electrons to flow in the circuit. Since this force, in volts, causes a movement of electrons, we call it an **ELECTROMOTIVE FORCE**, abbreviated **emf**.

DIRECT AND ALTERNATING CURRENT

In **DIRECT CURRENT (dc)** circuits electrons flow only in one direction. The polarity of the source voltage used in dc circuits does not change. A **BLOCK DIAGRAM** of a simple dc circuit is shown in Figure 8. In a

The following Practice Exercise questions cover the subjects which you have just studied. They are:

ELECTRICITY**CURRENT****SOURCE, LOAD AND CIRCUIT**

13. When an object gives up electrons it acquires a _____ charge and when it acquires an excess of electrons it acquires a _____ charge.
14. What is potential difference?
15. Two bodies have a potential of +8 units. What is the difference in potential between the two bodies?
16. One body has a potential of +15 units and another has a potential of -10 units. The difference in potential between the two bodies is (a) 25 units, (b) 5 units, (c) 15 units.
17. What is voltage?
18. What is the name given to the standard unit of measure of voltage?
19. A flow of electrons is called a _____ .
20. What is a conductor?
21. An ampere is a quantity of electrons. True or False?
22. 6,000,000,000,000,000 electrons is called a _____ .
23. How many milliamperes are there in 3 amperes?

24. A current of 350,000 microamperes is equal to _____ ampere.
25. What are the three basic parts of an electrical system?
26. Electron flow in a circuit is always from (+) to (-). True or False?
27. What is necessary besides a source and a load to produce a flow of electrons?
28. The force or pressure that causes electrons to flow in a circuit is called _____ .

block diagram the components of a circuit are represented by blocks. The arrows in Figure 8 indicate the direction of electron flow.

There are voltage sources available which cause electron flow to periodically change direction. In **ALTERNATING CURRENT (ac)** circuits the direction of electron flow does periodically change. A block diagram of a simple ac circuit is shown in Figure 9.

When the source polarity is as indicated by the solid plus (+) and minus (−) symbols, electron flow is in the direction of the solid arrows. When the source polarity reverses, as shown by the broken plus (−|−) and minus (−|−) symbols, electron flow is in the direction of the broken arrows.

The frequency, or rate of polarity change, of the source in Figure 9 is 60 CYCLES PER SECOND (60 cps). The International Unit now used to express a frequency is the HERTZ (Hz); therefore, 60 cycles per second is referred to as 60 Hz.

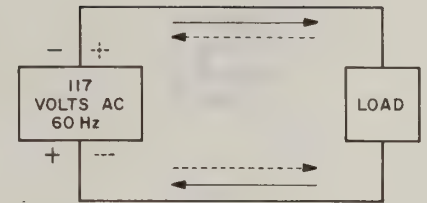


Figure 9

SYMBOLS

It is not always practical to draw circuits in the form of a block diagram, as in Figures 8 and 9. This is particularly true of more involved circuits. For convenience, symbols are used to represent the components in diagrams of most electric and electronic circuits. Letter abbreviations are also used in place of voltage, current, and other terms. Thus, symbols and letters are a form of shorthand used in electronics to save time and space.

The symbol for a battery, a group of single cells, uses long and short lines as shown in Figure 10. The negative terminal is the short line at the bottom of the symbol; the positive terminal is the long line at the top of the symbol. The lines at right angles to these terminals are the connecting leads. The letter E stands for electromotive force since the battery voltage is a force that causes current in a circuit.

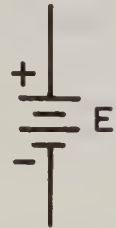


Figure 10



Figure 11

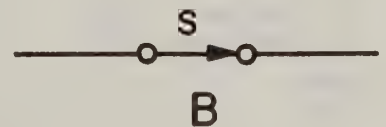
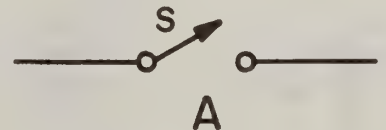


Figure 12

Figures 12A and 12B are the symbols for a simple switch. Figure 12A shows the switch in its open or OFF position while Figure 12B shows the



Figure 13



Figure 14



Figure 15

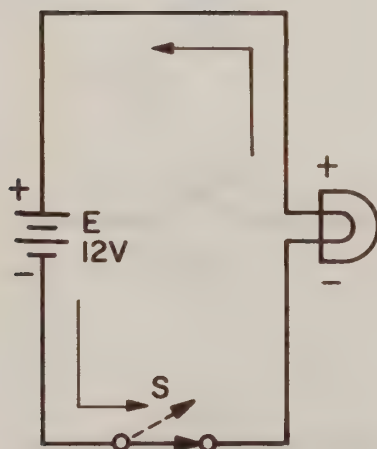


Figure 16

switch in its closed or ON position. The letters S or SW are often used with the switch symbol.

Figure 13 is the symbol for an incandescent lamp such as those in flashlights, automobiles, and homes. However, it is not the symbol for a fluorescent lamp.

Figure 14 is the symbol we will use to designate a motor. In some drawings, the circle may contain only the letter M.

Figure 15 is the symbol for a device which opposes electric current and produces heat when electric current is forced through it.

There are many other symbols which are commonly used to designate various components and devices. At this moment we are interested in only showing a few of the symbols and ways of using them.

SCHEMATIC DIAGRAMS

Now that we have introduced a few of the symbols used by technicians and engineers in the field of electricity and electronics, let's see how they look in diagrams.

Referring to Figure 16, a battery symbol is shown at the left side of the diagram. This symbol is labeled to indicate that the voltage is 12 volts dc. The symbol at the right side of the diagram indicates that the load is an incandescent lamp. The symbol at the bottom of the diagram represents a switch.

When the switch is in the OFF position, as indicated by the dashed arrow on the switch, there is no complete path for electron flow and the lamp does not light. When the switch is thrown to the ON position, as indicated by the solid arrow on the switch, the circuit is completed. As shown, electron flow is from the negative battery terminal, through the switch, through the load and back to the positive battery terminal. The arrows show the direction of current flow while the plus and minus signs at the load show the polarity of the potential difference or voltage across the load.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

DIRECT AND ALTERNATING CURRENT

SYMBOLS

SCHEMATIC DIAGRAMS

29. In dc circuits the current is constantly changing direction. True or False?
30. What is the difference between dc and ac?
31. A source which has a frequency of 50 Hz is considered to be a dc source. True or False?
32. The International Unit for frequency is the _____ .
33. A block diagram is a pictorial representation of a circuit. True or False?
34. The symbol of Figure 10 is used to represent either an ac or dc source. True or False?
35. Describe the symbol for a battery or group of single cells.
36. Symbols and letters used on schematic diagrams require more space and time and therefore they are not practical. True or False?

37. The letter E, when used on a schematic diagram, stands for _____ .
38. In the circuit of Figure 16, electron flow stops when switch S is opened. True or False?
39. A diagram which uses special symbols to represent circuit components and connections is called a _____ .
40. Schematic diagrams show the physical location of components in a circuit. True or False?

Notice that the polarity of the voltage across the load is the same as that across the battery or source. This is because the source and load are connected together with the wires that complete the circuit.

The diagram shown in Figure 16 is called a **SCHEMATIC DIAGRAM**. This type of diagram shows the electric connections of the components in a circuit. However, it **DOES NOT** show the physical locations of the components in a circuit. The polarity of the battery voltage and the polarity of the voltage across the load are not always shown on a schematic diagram.

The schematic diagram of Figure 17 shows the same type of circuit as in Figure 16. The only difference is the manner in which the voltage source is connected. Here, the battery symbol indicates that the battery has been reversed so that the current flow is now in the opposite direction of that shown in Figure 16. In both circuits, however, the lamp is lit when the switch is closed, regardless of the direction of current flow. No current can flow unless there is a **COMPLETE** path. Therefore, when the switch is opened (the dashed arrow), all current stops.

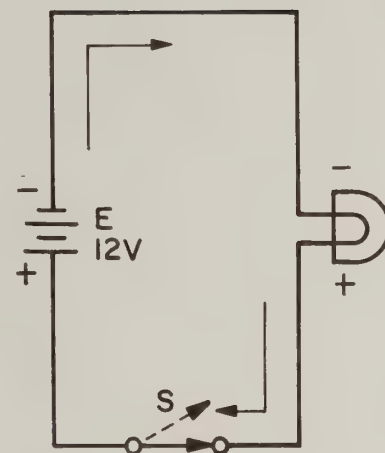


Figure
17

SUMMARY

In this lesson you have become familiar with many of the basic ideas common to all electric and electronic work. These ideas are like building blocks. Even the most elaborate electronic equipment is usually analyzed in terms of its simple component parts as drawn in schematics. The concepts of source, circuit and load apply just as they do to the simple illustrations shown in this lesson.

The source of electric energy must be capable of causing an electric current to flow through the circuit and the load. The load can be any electric or electronic device designed to be operated when the available source is applied. That is, if the source voltage is 120 volts ac, the load must be designed to operate properly on 120 volts ac. The circuit is the wiring, switches, outlets, plugs, etc., which connect the source to the load so that the electric energy, available from the source, may be used by the load.

The units and terms introduced here will be encountered over and over again. Through continued use they will become a common part of your vocabulary. Your understanding of them is an extremely powerful tool.

IMPORTANT DEFINITIONS

In this and the following lessons, important words are printed in **BOLD-FACE** type. Most of these words are listed in the back of the lesson for easy reference. Learn them as you will be using them over and over. When you review a lesson, be sure to also include the Important Definitions list.

ALTERNATING CURRENT — A flow of electrons which periodically reverses or changes direction. Abbreviated **ac**.

AMPERE — The basic unit of measure of electric current. One ampere represents approximately 6,000,000,000,000,000 electrons (one coulomb) moving past a point in one second.

ATOM — A small particle of matter consisting of a central nucleus and one or more rotating electrons.

BLOCK DIAGRAM — A drawing in which components of a circuit are represented by blocks.

CHARGE — A quantity of electricity. The bases of electric charges are the negative charge of the electron and the positive charge of the nucleus.

CIRCUIT — A complete electrical system which provides the electron path between the source and load.

CONDUCTOR — A material with many free electrons.

COULOMB — The unit of electron quantity equal to approximately 6,000,000,000,000,000 electrons.

CURRENT — A flow of electrons from a point of more negative potential to a point of more positive potential.

DIRECT CURRENT — A flow of electrons moving only in one direction in a circuit. Abbreviated **dc**.

IMPORTANT DEFINITIONS (Continued)

ELECTRICITY — A term used to describe energy in either its potential or kinetic form.

ELECTROMOTIVE FORCE — The force which causes motion or flow of electrons. Abbreviated **emf**.

ELECTRON — A small particle which rotates around the nucleus of the atom. The electron has a negative electric charge.

ELECTRONICS — The study of the control and use of electricity or electric energy.

ELEMENTS — Types of materials which can be divided into atoms without losing their characteristics.

ENERGY — The ability to do work.

FREE ELECTRONS — Electrons which are held loosely in an atom and are available to form an electric current.

ION — An atom which is not electrically neutral. Atoms with a positive charge are called positive ions, while atoms with a negative charge are called negative ions.

KINETIC ENERGY — Energy of motion.

LOAD — The part of an electrical system which uses the flow of electrons to perform a useful function.

MICROAMPERE (μA) — One-millionth of an ampere (.000001 ampere).

MILLIAMPERE (mA) — One-thousandth of an ampere (.001 ampere).

MOLECULES — Particles made up of one or more atoms.

IMPORTANT DEFINITIONS (Continued)

NUCLEUS — The central portion of an atom, around which the electrons rotate. The nucleus has a positive electric charge which holds the electrons in their orbits.

POTENTIAL — The ability of a charged body to do work.

POTENTIAL DIFFERENCE — The measure of the difference in charge between two bodies.

POTENTIAL ENERGY — Energy at rest.

SCHEMATIC DIAGRAM — A special type of drawing used in electronics to represent circuit components and connections. This type of diagram uses simplified symbols to show electric connections, but it does not show the physical layout or part structure.

SOURCE — The part of an electrical system which provides the difference in potential.

STATIC ELECTRICITY — The electric charge which results when electrons are removed or added to a substance.

VOLT — The basic unit of measure of electric pressure or voltage.

VOLTAGE — Another term for difference of potential or electric pressure.

WORK — The use of energy.

PRACTICE EXERCISE SOLUTIONS

1. **potential** — An object at rest has potential energy.
2. **kinetic** — An object in motion has kinetic energy.
3. **work** — The use of energy is work.
4. **mechanical; electric**
5. **controlled** — To do useful work, such as develop a television picture, electricity must be controlled.
6. **(b) molecule** — All molecules are made up of one or more atoms.
7. **(c) electrons** — The electrons revolve in orbits around the nucleus.
8. **negative; positive** — The difference in the charges along with the momentum of the electron keeps it in a stable orbit around the nucleus.
9. **element.**
10. **Like charges repel and unlike charges attract.**
11. **A free electron** is an electron in the outer orbit of an atom that is loosely bound and free to drift from atom to atom.
12. **True** — An atom with a positive charge would be a positive ion while an atom with a negative charge would be a negative ion.
13. **positive; negative**
14. **Potential difference** is the potential of a charged body with respect to another charged body or to a body with a neutral charge.

PRACTICE EXERCISE SOLUTIONS (Continued)

15. 0 units. Both bodies are at the same potential and thus no difference in potential exists.
16. (a) 25 units.
17. Voltage is another name for difference in potential.
18. Volt.
19. current.
20. A conductor is a material such as copper which has many free electrons.
21. False — An ampere is a rate of electron flow — one coulomb of electrons per second.
22. coulomb.
23. 3000 — One ampere is equal to 1000 milliamperes. Thus, 3 amperes equal 3×1000 or 3000 milliamperes.
24. .35—To convert microamperes to amperes, divide by 1,000,000. Thus, $350,000 \text{ microamperes} \div 1,000,000$ equals .35 ampere.
25. Source, load and circuit. — The source provides the difference in potential, the load uses the flow of electrons and the circuit provides the electron path.
26. False — Electrons flow from (—) to (+) in a circuit.
27. A complete circuit or path is needed to obtain electron flow.

PRACTICE EXERCISE SOLUTIONS (Continued)

- 28. **ELECTROMOTIVE FORCE** — abbreviated EMF.
- 29. **False** — In dc circuits current flows only in one direction.
- 30. The abbreviation dc stands for direct current which means that electrons flow only in one direction. The abbreviation ac stands for alternating current which means that electron flow periodically reverses direction.
- 31. **False** — When a frequency is given (in this case a frequency of 50 Hz), it indicates the rate at which the signal is changing polarity.
- 32. **hertz.**
- 33. **False** — In a block diagram a component, or components, of a circuit is represented by blocks.
- 34. **False** — The symbol of Figure 10 represents a dc source while the symbol of Figure 11 represents an ac source.
- 35. The symbol for a battery or group of single cells uses long and short lines as shown in Figure 10. The negative terminal is the short line at the bottom of the symbol; the positive terminal is the long line at the top of the symbol.
- 36. **False** — Symbols and letters used on schematic diagrams are a form of shorthand and are used to save time and space.
- 37. **electromotive force.**
- 38. **True** — Opening switch S breaks the complete path for electrons, thereby halting their flow.
- 39. **schematic.**
- 40. **False**

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

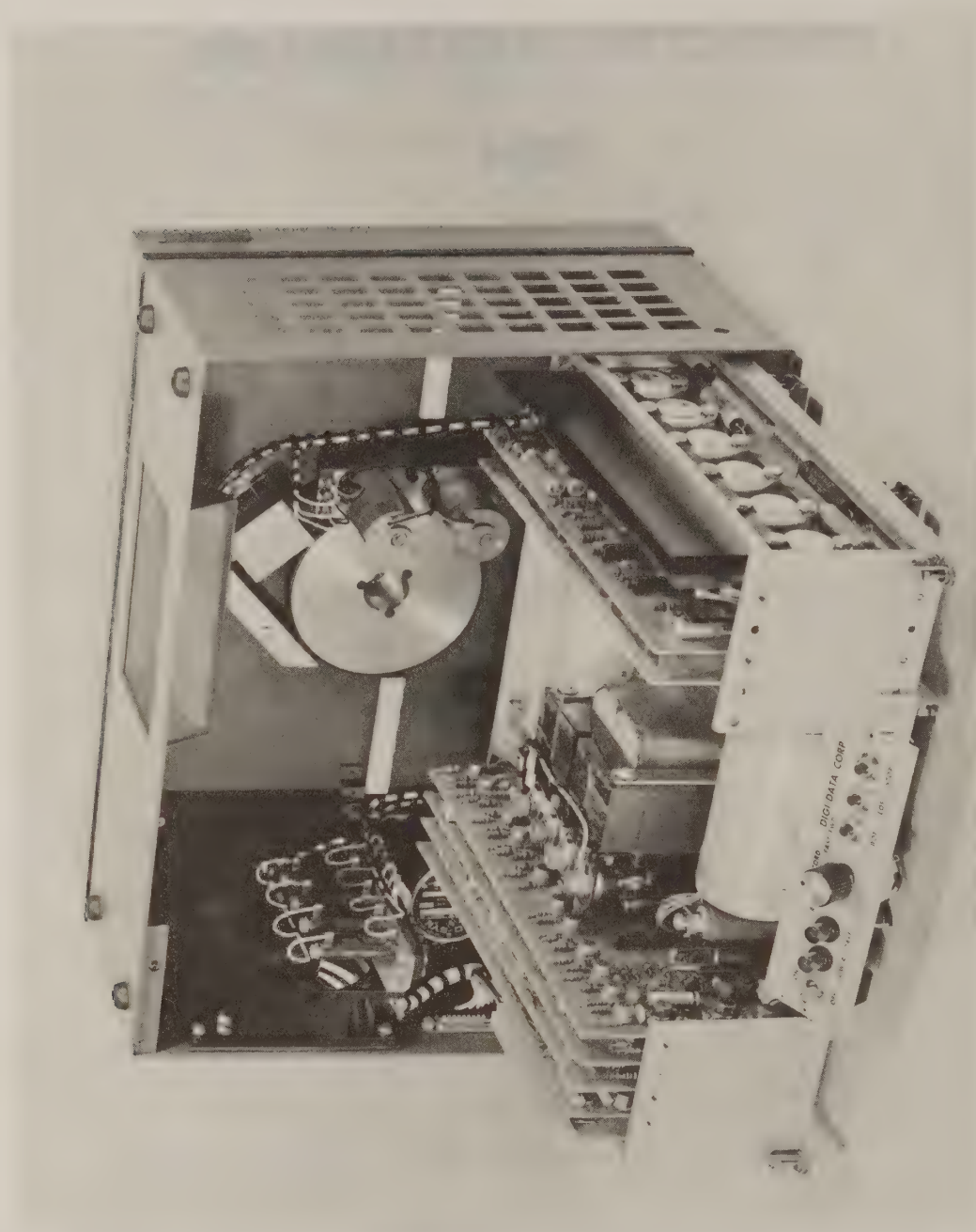
LESSON CODE
1001A

Example: An elephant has
A ☐
B ☐
C ☐
D ☒
A. wings. B. fins. C. feathers. D. a trunk.

1. A ☐ In electric circuits, a switch is
B ☐ (A) usually used to control the electricity. (B) always used. (C) used in place of
C ☐ a load. (D) the source of energy.
D ☐
2. A ☐ An electron
B ☐ (A) has a negative charge. (B) has no charge. (C) has a positive charge. (D)
C ☐ may be either positive or negative.
D ☐
3. A ☐ Electrons drifting from atom to atom in a material
B ☐ (A) are free electrons. (B) are bound electrons. (C) all go in the same direction.
C ☐ (D) have a positive charge.
D ☐
4. A ☐ In electric circuits, the **ELECTROMOTIVE FORCE** is measured in
B ☐ (A) amperes. (B) volts. (C) microamperes. (D) coulombs.
C ☐
D ☐
5. A ☐ Electric current is considered to be the movement of electrons
B ☐ (A) from a negative point to a positive point. (B) in orbit around a nucleus.
C ☐ (C) in a random fashion. (D) from left to right.
D ☐
6. A ☐ The basic unit of measurement of electric **CURRENT** is
B ☐ (A) the volt. (B) the milliampere. (C) the ampere. (D) the coulomb.
C ☐
D ☐
7. A ☐ Direct current
B ☐ (A) flows from **POSITIVE** to **NEGATIVE** in each circuit. (B) flows in alternate
C ☐ directions in each circuit. (C) has a different unit of measure than alternating
D ☐ current. (D) flows in one direction in a particular circuit.
8. A ☐ A schematic diagram
B ☐ (A) shows the electric connections of the components in a circuit. (B) shows
C ☐ the physical positions of the components in a circuit. (C) is used only when the
D ☐ source voltage is ac. (D) is used only when the source voltage is dc.
9. A ☐ In Figure 16, with the switch in the open position,
B ☐ (A) the source voltage causes alternating current in the circuit. (B) the circuit
C ☐ is complete and the lamp glows. (C) no current flows in the circuit. (D) the
D ☐ source voltage reduces to zero.
10. A ☐ All complete electric systems must have
B ☐ (A) just a switch and a dc source. (B) an ac source and a load. (C) an ac or
C ☐ dc source, a load and a complete circuit. (D) just a load and a complete path
D ☐ for current.

CONDUCTORS AND RESISTORS

1004



This photo shows an inside view of a digital tape recorder. Most of the circuitry is mounted on printed circuit boards.

Courtesy Digi-Data Corp.

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Persons of the highest intelligence never cease to learn and any person, whatever may be his station in life, who devotes a share of his time to self betterment through home study courses will never regret the time thus spent.

—C. Haile

CONDUCTORS AND RESISTORS

In electric circuits we have a source of energy which we call the electromotive force, or voltage. We measure this force in volts. In a complete circuit the source voltage causes electrons to move from the negative terminal of the source through the connecting wires to the load. The electrons continue through the load and the remaining connecting wires to the positive terminal of the source. We call this movement of electrons an electric current, and we measure the current in amperes.

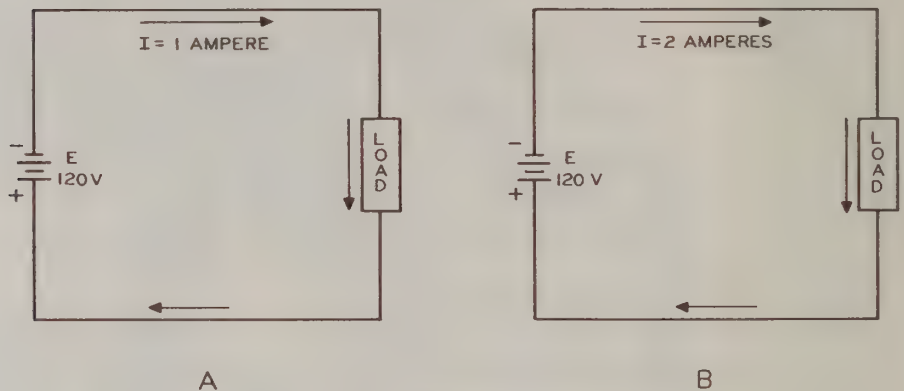


Figure 1

Figures 1A and 1B show two circuits that appear to be identical. However, the current in Figure 1A is 1 ampere while the current in Figure 1B is 2 amperes, even though the voltage in each circuit is 120 volts. Assuming that the connecting wires are the proper type so that they have no noticeable effect on the amounts of current in these circuits, the only things that can cause these differences in current are the loads. That is, the load in Figure 1A must be different from the load in Figure 1B.

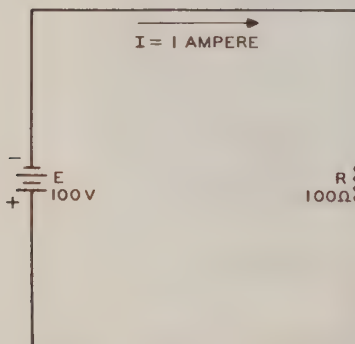


Figure 2

RESISTANCE

Any device that is used as a load—for example, a light bulb or a toaster—opposes current in an electric circuit. This is a physical property that is determined by the manner in which the device is constructed. We call this property the **RESISTANCE** of the device. Therefore, resistance is the property of a device which opposes current in an electric circuit.

It is convenient to use a symbol to represent the resistance of any device. This symbol is shown in the schematic diagram of Figure 2 and is identified

by the letter **R**. In this simple circuit the voltage source **E** is forcing current **I** through resistance **R**. As indicated by the arrow, the direction of current is from the negative terminal of the voltage source, through the resistance and back to the positive terminal of the voltage source.

The basic unit of resistance measurement is the **OHM**, in honor of the German physicist, Georg Simon Ohm. The Greek letter Ω (capital omega) is often used instead of writing out ohm or ohms. Thus, 100Ω means 100 ohms.

Resistance is a property that ordinarily does not change, even though the voltage in a circuit may be changed. However, devices with different amounts of resistance may be connected into a circuit to control the amount of current. Since resistance opposes current, **THE CURRENT IN A CIRCUIT IS INVERSELY PROPORTIONAL TO THE RESISTANCE IN THE CIRCUIT**. That is, when the resistance is increased, the current decreases; when the resistance is decreased, the current increases.

Figure 3 shows an electric circuit in which the current is 2 amperes. The current in this circuit is twice that of the current in Figure 2. However, the speed of the electric current in both circuits remains relatively constant. If the voltage is increased or the resistance is decreased, the speed of the electrons does not change, even though the current increases. The increased current is caused by the movement of more electrons at the same speed.

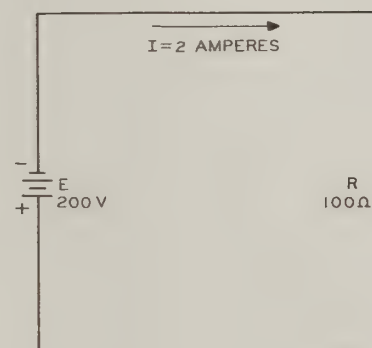


Figure
3

CONDUCTANCE

There are times that it is more convenient to consider how well a circuit conducts or passes current than to consider the resistance it offers. The ease with which a circuit conducts current is called its **CONDUCTANCE**. The letter **G** is used to represent conductance which is the reciprocal of resistance. That is, conductance is found by dividing the number 1 by the resistance:

$$\text{Conductance} = \frac{1}{\text{Resistance}} \text{ or } G = \frac{1}{R} \quad (1)$$

The unit of conductance is the **MHO**, or the more recently adopted **SIEMENS**. For example, if the resistance is 1 ohm, the conductance is $1/1$ or 1 mho (1 siemens). If the resistance is 2 ohms, the conductance is $1/2$ or .5 mho (.5 siemens).

Since there is an inverse relationship between conductance and resistance, whenever the resistance in a circuit is increased, the conductance is decreased. Whenever the resistance is decreased, the conductance is increased.

CONDUCTORS, RESISTORS AND INSULATORS

Wires play an important role in our world of today. They carry electricity from large and small electric power plants, sometimes for hundreds or thousands of miles, to the homes, factories and offices where it is used. Wires from the telephone exchange to your home and between exchanges permit rapid and efficient communication between points thousands of miles apart.

Television receivers and transmitters, radio communication equipment, guided missile controls, medical research instruments and computers are assemblies of numerous parts connected together with wires to form the complete unit.

The most common types of wires are metal cylinders of uniform diameter. They are made in many sizes with diameters ranging from those of almost invisible hair-like filaments to rods an inch or more thick. Regardless of its size or its use, the purpose of a wire used in an electric circuit is to provide a path for electricity. To do this, it must be a **CONDUCTOR** of electricity.

To control electricity, it is not enough to simply provide a complete current path. In addition, the electricity must be confined to the desired paths by the proper use of materials called **INSULATORS**. Insulators prevent electric current from taking a path which is not desired.

All materials cannot be classified as being either conductors or insulators. Many of them allow too much electric current to be good insulators but not enough to be good conductors. These materials possess the property called resistance. Unfortunately, there are no sharply defined lines between conductors, resistors and insulators. Low-resistance materials may be used as resistors in some applications and as conductors in other applications. High-resistance materials may be used as resistors in some applications and as insulators in other applications.

Copper is usually considered the standard of conducting materials. Other conducting materials are rated with reference to copper. For example, the resistance of platinum is 6.16 times the resistance of copper, while the resistance of mercury is 55 times that of copper. As conductors, these materials are not as good as copper. Silver, on the other hand, has a relative resistance of .95, which means that it is a better conductor than copper.

CONDUCTORS

Copper wire is probably the most common conductor in use today. In its simplest form, it is a solid wire. It usually has some type of insulation

around it to prevent electrical contact at any point except where contact is desired.

Quite often, wires must be used very close to each other, and one wire may even bend back upon itself. Should the metal of one wire touch that of another, the electricity could follow a different, possibly shorter path than is desired. This condition is called a **SHORT CIRCUIT**, or a short. To prevent this condition, the metal wire is covered with insulation such as rubber, enamel, cotton, silk, nylon or plastic.

Wire used to complete circuits within electronic equipment is commonly called **HOOKEUP WIRE**. Figure 4A illustrates one type of hookup wire in which a solid conductor is insulated with a layer of plastic or rubber. This provides an excellent conductor which is well insulated, easy to work with, and very economical.

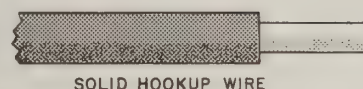


Figure
4 A

Although solid copper hookup wire of the commonly used size is bent quite easily, it will break if flexed too often. To obtain a more flexible wire, it is customary to make up a conductor from a number of small, solid wires. The smaller sizes of copper wire are extremely flexible. Even when a number of them are twisted together, somewhat like the threads in a piece of string, the resulting conductor still remains flexible. Because it is made of a number of small wires, hookup wire of this type is known as **STRANDED HOOKUP WIRE**.

Figure 4B shows a stranded hookup wire insulated with a coating of rubber or plastic. As both the stranded wire and the insulation are very flexible, this is a general purpose type of hookup wire for use where there is considerable movement of the wire. The flexibility reduces the possibility of wire breakage.

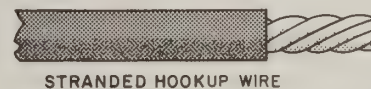


Figure
4 B

WIRE CHARACTERISTICS

Perhaps the greatest advantage of electric energy is that it can be carried great distances over reasonably sized wires with very little loss. At first thought, the size of the wire and the material of which it is made might not appear important. However, the material, diameter, length and temperature of the wire, as well as the insulation on it, must be considered when selecting wire to be used for any electric purpose. Let's examine the first four of these factors, and see how they affect the resistance of wire.

The material from which a wire is made has a great effect on its resistance. While silver is the best practical conductor, copper is very good and so readily available that it is the most widely used metal for wires of all sizes. However, for some purposes, wires are made of other metals or of mixtures of two or more metals called alloys.

The next factor which determines the resistance of a wire is its diameter or area. Due to the small size of most wire, the unit for the measurement of wire diameters is the **MIL**, which is equal to one-thousandth of an inch (.001 inch). Since it is the cross-sectional area of a wire that determines its resistance and ability to carry current, the diameter is used to compute the area in **CIRCULAR MILS**. The circular mil is a unit of area for a **CIRCLE** one mil in diameter. (Don't confuse the circular mil area with the area of a rectangular cross section where the area is equal to the length $\times$ width.) The circular mil cross-sectional area of a wire is equal to the square of its mil diameter. For example, a wire having a diameter of 1 mil has a cross-sectional area of 1×1 , or 1 circular mil, while a wire having a diameter of 5 mils has a cross-sectional area of 5×5 , or 25 circular mils.

Since the circular mil area is equal to the square of the mil diameter, the resistance of a wire varies inversely as the square of the mil diameter. Thus, a 2 mil wire has $1/4$ the resistance of a 1 mil wire. **THE LARGER THE DIAMETER OF A WIRE, THE LESS ITS RESISTANCE TO CURRENT, AND THE MORE CURRENT IT CAN CARRY.**

The next factor affecting the resistance of wire is its length. A longer wire has greater resistance because the electricity has farther to travel. The effect of the length is such that a wire two feet long has a resistance twice that of a similar wire one foot long.

Temperature also affects the resistance of a wire. Whenever electricity passes through a conductor, it produces a certain amount of heat. The resistance of the conductor changes with temperature. The amount of this change varies with different metals, but generally the resistance increases with an increase of temperature. For the average application, where the current level is not extremely high, the temperature change is not as important as the other factors affecting the resistance.

To sum up, the resistance of a wire varies:

1. with the material;
2. inversely as its circular mil area;
3. directly with its length; and
4. with temperature changes.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

RESISTANCE

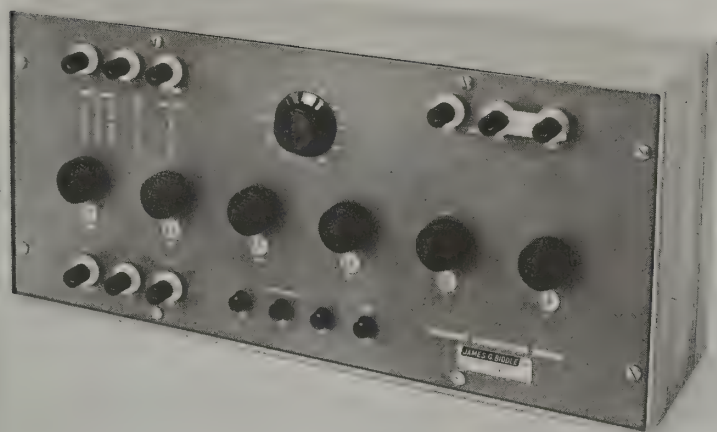
CONDUCTANCE

CONDUCTORS, RESISTORS AND INSULATORS

CONDUCTORS

1. Resistance is that property which opposes _____ in an electric circuit.
2. The unit of measurement of resistance is the (a) volt, (b) ohm, (c) ampere.
3. In the electric circuit shown in Figure 2, an increase in voltage causes (a) an increase in the speed of the electric current, (b) a movement of more electrons.
4. In the circuit shown in Figure 3, when the voltage is doubled, (a) the resistance doubles, (b) the current doubles.
5. In the circuit shown in Figure 3, if the resistance is increased, (a) the source voltage is increased, (b) the current is increased, (c) the conductance is decreased.
6. The wire used in electric circuits provides an easy path for electricity. True or False?

7. Which of the following is the poorest conductor? (a) Copper. (b) Mercury. (c) Silver.
8. Name one desirable feature of solid wire.
9. Name one advantage of stranded wire over solid wire.
10. What type of wire would you choose for a line cord that connects your radio (or TV set) to the wall outlet—solid or stranded?



Wheatstone bridges can be used to measure resistance with a high degree of accuracy.

Courtesy James G. Briddle Co.

Appendix A at the back of this lesson illustrates how these factors are used to determine the actual resistance of a conductor.

Copper wire, by far the most common type of wire, is made in many sizes. It is often important to know the resistance per foot, or per 100 feet, of a piece of copper wire of a given size. Therefore, in Appendix B at the back of this lesson, the Brown and Sharpe copper wire table is given with instructions on how to use it. Notice that the larger the gauge number of wire, the smaller the wire diameter.

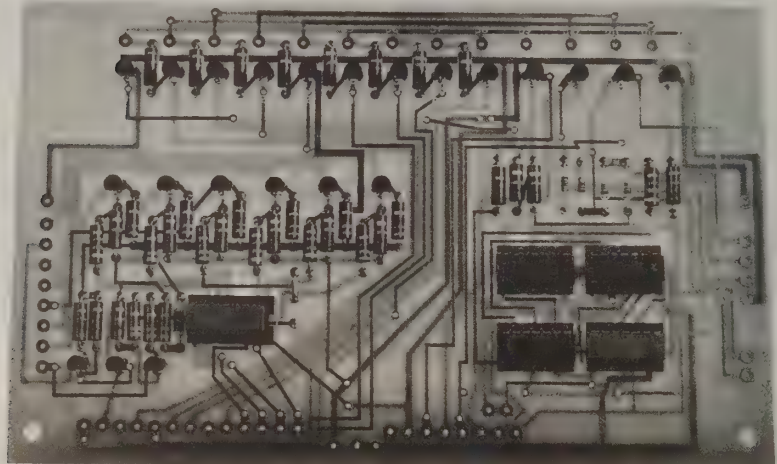
PRINTED AND INTEGRATED CIRCUITS

Many electronic devices manufactured today use PRINTED CIRCUITS. The parts (components) in these circuits are connected by metal strips bonded to an insulating base.

One common method of making printed wiring boards is to bond a thin sheet of copper to a plastic base, and etch away all copper except for the conductive paths that will serve as the circuit connections. This leaves a net-

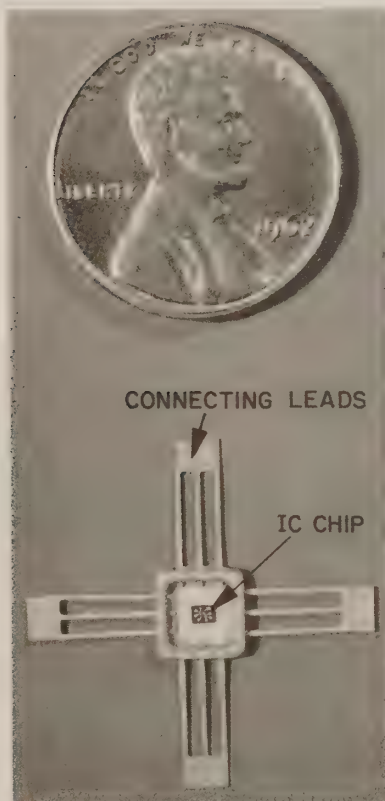
CONDUCTORS AND RESISTORS

work of conductive strips on that side of the plastic base. Connecting leads of the parts are inserted through holes drilled in the base, and are soldered to the conductive strips. Some boards have copper conductive strips on both sides of the board.



A glass printed circuit board reveals the conductive strips on the backside of the board (light gray strips).

Courtesy Micro Instrumentation and Telemetry Systems Inc.



This integrated circuit chip shows the external connecting leads which are shorted together to prevent static electric damage to the chip. These leads will be cut (unshorted) and the entire chip will be encapsulated in a protective covering.

Courtesy General Electric Co.

Printed circuit wiring is ideal for mass production of transistor radios, computer circuits and many other types of electronic equipment. Once the parts layout and pattern of conductive strips have been determined for a given circuit, large numbers of printed circuit boards can be produced for that circuit. Building the circuit is simply a matter of adding the parts to the board and soldering the connections.

Conductive paths are deposited in the form of metallic film on an insulating base in integrated circuits. Some of these microminiature circuits are so tiny that the complete circuit would fit inside the letter "o" on this page. The conductive paths between various parts of the circuit are so small that they are invisible to the unaided eye.

RESISTORS

Whenever a voltage source is connected to a load, it forces current through the load. With a fixed voltage source, such as a battery, the amount of

current that passes through the load depends on the total resistance of the circuit. The desired current is sometimes obtained by placing resistance at proper places in the circuit to control the amount of current. This additional resistance is often obtained by using components called **RESISTORS**. A resistor is a device which offers a certain amount of opposition to the flow of electric current.

Certain metals and other materials are used to construct resistors to a desired resistance. For example, **RESISTANCE WIRE** can be made from certain metal alloys. Common elements in alloys used for this purpose are nickel, chromium and iron.

Carbon, graphite and tin oxide are three other substances commonly used in the manufacture of resistors. Because resistors are widely used in electronic circuits, they are manufactured to provide a wide range of resistance values and come in a great variety of sizes.

Wire-Wound Resistors

A typical **WIRE-WOUND RESISTOR** is shown in Figure 5A. Resistance wire is wound on a porcelain or ceramic tube and attached to terminal lugs at each end. The turns of resistance wire are spaced so they do not touch and cause a short circuit in part of the winding. To insulate the entire assembly and prevent damage to the resistance wire, the unit is covered with an insulating material, often a cement or vitreous enamel, which is baked on at a high temperature.

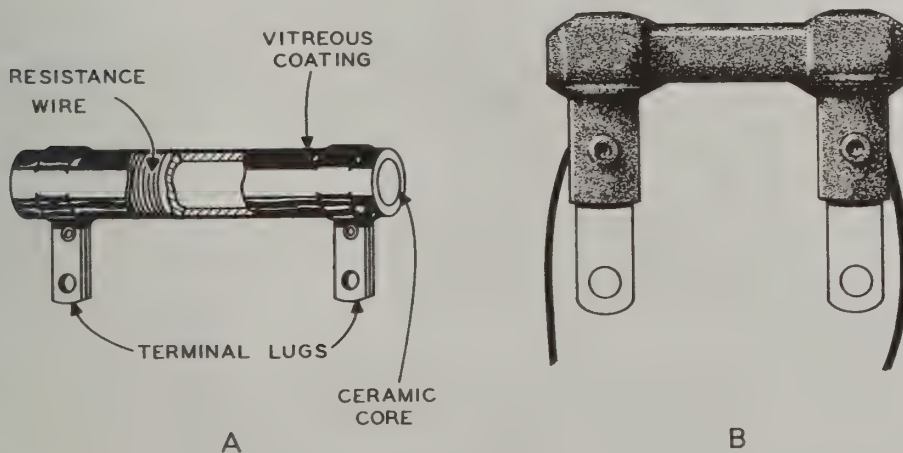


Figure 5

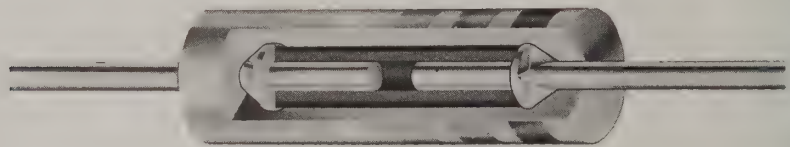
For convenience in making circuit connections, wire leads are often riveted to the terminals of a wire-wound resistor as shown in Figure 5B. The lugs are often extended as shown to allow an alternate means of connection.

Depending on the length, diameter and material of the resistance wire, the resistors of Figure 5 have some specific resistance, and maintain this value with practically no change when used properly. Thus, no matter what the type or size, these units are classed as **FIXED RESISTORS**. For general use, wire-wound fixed resistors are made in standard values from about 1 ohm to about 250,000 ohms.

In addition to ceramic or porcelain tubes, other insulating materials are used as a base on which the resistance wire may be wound. Also, the finished product may be flat, square or almost any shape to meet the requirements of various applications.

Carbon Resistors

A very common type of resistor employs a "mix" made of a conducting material and a filler or binder. The conductor is usually carbon or graphite while the filler is clay or bakelite. The binders or fillers are insulating materials, and by combining them in the proper proportions with conducting materials, the resulting mix will have the desired resistance characteristics. After the mix is made, it is usually heated and molded under pressure into the form of a solid rod. The rod may be cut into suitable lengths and connecting wires attached to the ends.



*A cutaway view of a carbon resistor shows its internal construction.
Courtesy IRC Division of TRW Inc.*

Since the conducting material used in the mix is usually carbon, units made by this general method are known as **CARBON RESISTORS**. These resistors are small in size and are made in values ranging from about an ohm to several million ohms.

When several carbon resistors are installed close to each other, as often happens in electronic equipment, there is a possibility that they may touch each other or the metal chassis on which they are mounted. When a contact of this kind occurs, it provides an undesirable electric path or short circuit.

To prevent shorts of this kind, carbon resistors are manufactured as shown in Figure 6. The metal beads on the ends of the connecting lead wires are imbedded in the carbon mix and the unit is enclosed in an insulating jacket. Thus, the conducting material of the resistor cannot come in contact with other parts.

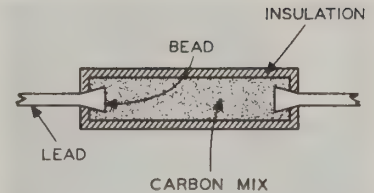
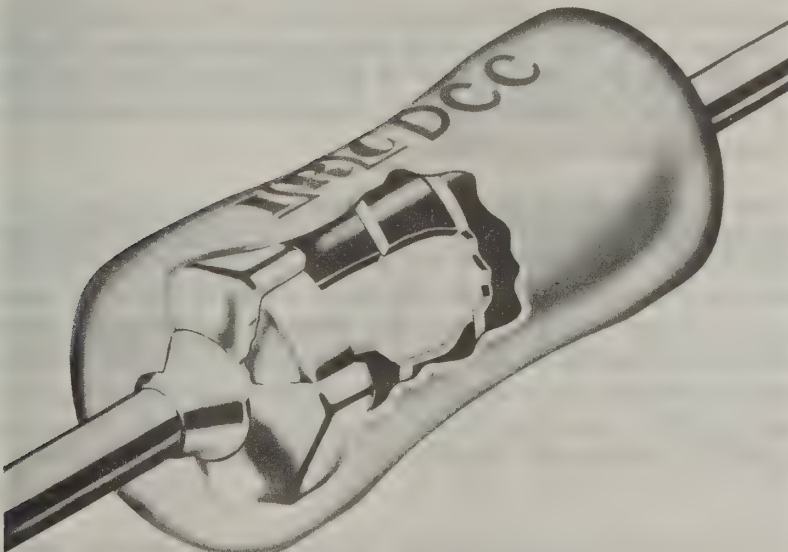


Figure
6

Deposited Film Resistors

Often similar to a carbon resistor in appearance and size, **DEPOSITED FILM RESISTORS** consist of a thin coating of conducting material sprayed on the surface of a small glass or ceramic rod. The conducting material may be any one of several materials including carbon, graphite or metalized



A cutaway view of a coated deposited film resistor shows its internal construction.

Courtesy IRC Division of TRW Inc.

oxide. To complete the unit, the rod is sometimes enclosed in a ceramic or bakelite tube. Like carbon resistors, deposited film resistors are available in a wide range of resistances.

Diffused Resistors

In an integrated circuit, resistors are formed by adding impurities (doping) to the silicon material that serves as the basic substance of the circuit. The doping process consists of allowing (diffusing) a foreign material such as aluminum to enter (diffuse) into the silicon at high temperatures, so that the aluminum changes the resistance of the silicon.

In a **DIFFUSED RESISTOR**, the resistance is often expressed in ohms per square (ohms/sq. or $\Omega/\square$) of the doped surface. The meaning of this unit is illustrated by the diagrams of Figure 7.

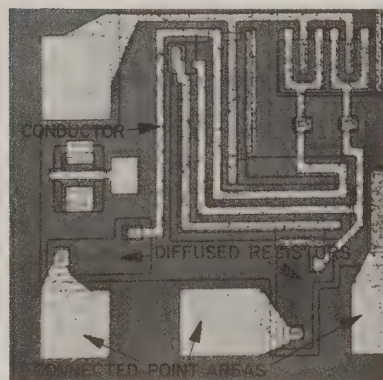
Referring to Figure 7A, let's assume a piece of doped silicon 1 mil square has a resistance of 2 ohms. This means we would measure 2 ohms between points A and B. If we place two of the silicon squares end to end, as in Figure 7B, we double the length of the current path. This increases the resistance between points C and D to 4 ohms. Thus, the longer the current path between the end points, the greater the resistance.

If two squares are placed side by side, as in Figure 7C, we double the width of the current path. This reduces the resistance between points E and F to half the resistance of a single square. In this example, the resistance reduces to $1/2 \times 2$ ohms, or 1 ohm. Thus, the wider the current path between the end points, the smaller the resistance.

Suppose we double the **LENGTH** of the path **AND** the **WIDTH** of the path, as in Figure 7D. The increase in width offsets the increase in length, so the resistance in Figure 7D is 2 ohms, the same as that of the 1 mil square in Figure 7A. Notice that a square of this material has the same resistance, regardless of the area of the square. Knowing the $\Omega/\square$ rating, the designer can produce resistors in an integrated circuit by merely regulating the ratio of length to width in the doped silicon material—for example, to increase resistance we can increase the length of the resistor area.

RESISTOR RATINGS

Resistors have several ratings which are determined by their physical characteristics. The first of these ratings is resistance, measured in ohms, which depends on the material used, its cross-sectional area and its length.



A magnified view of an integrated circuit chip shows how a diffused resistor is constructed.

Courtesy Radio Corporation of America

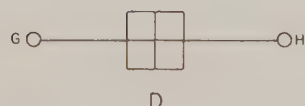
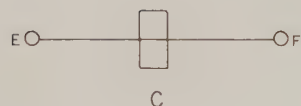
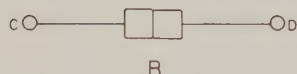
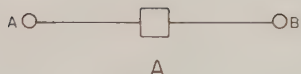


Figure 7

The following Practice Exercise questions cover the subjects which you have just studied. They are:

WIRE CHARACTERISTICS

PRINTED AND INTEGRATED CIRCUITS

RESISTORS

WIRE-WOUND RESISTORS

CARBON RESISTORS

DEPOSITED FILM RESISTORS

DIFFUSED RESISTORS

11. Much of the wire used for the electrical circuits in homes has a diameter of about 80 mils. What is its area in circular mils?
12. A 3 mil wire has (a) $\frac{1}{3}$ the resistance of a 1 mil wire, (b) $\frac{1}{6}$ the resistance of a 1 mil wire, (c) $\frac{1}{9}$ the resistance of a 1 mil wire.
13. The resistance of copper wire decreases (a) as the diameter decreases, (b) with an increase in length, (c) as the circular mil area increases.
14. Temperature has no effect on the resistance of wire. True or False?
15. Copper wire is the most common type of wire. True or False?
16. From the table of Appendix B, which is larger in diameter, No. 20 or No. 40 wire?
17. Using the table of Appendix B, what is the resistance of 2000 feet of No. 18 copper wire?

18. Printed circuit wiring is almost never used in electronic equipment. True or False?
19. One use of a resistor is to control current. True or False?
20. Wire-wound resistors are usually made with (a) copper wire, (b) silver wire, (c) resistance wire.
21. Carbon resistors are 100% carbon. True or False?
22. Deposited film resistors consist of a thin coating of _____ material sprayed on the surface of a small glass or ceramic rod.
23. In a _____, the resistance is often expressed in terms of ohms per square of the doped surface.
24. Doubling the width of the current path of a diffused resistor doubles the resistance. True or False?

It is hard to manufacture a resistor with an exact number of ohms of resistance. Therefore, most resistors carry a **TOLERANCE** rating. For example, consider a resistor specified as having 10,000 ohms of resistance with a tolerance of 10%. Its actual resistance may be anywhere between 9000 and 11,000 ohms. To find these tolerance limits, we simply take 10% or .1 of 10,000 (which is 1000), add it to 10,000 ($10,000 + 1000 = 11,000$) to get the upper resistance limit, and subtract it from 10,000 ($10,000 - 1000 = 9000$) to get the lower resistance limit.

The electric current carried by a resistor produces heat. The heat intensity depends on both the resistance and the current. The more the current, the greater the heat the resistor must radiate into the surrounding air. The **WATTAGE RATING** of a resistor indicates how much heat it can safely dissipate. This rating depends on the physical size of the resistor. The **LARGER THE PHYSICAL SIZE** of a resistor, the greater its heat radiating surface area. **THEREFORE, A PHYSICALLY LARGER RESISTOR CAN SAFELY DISSIPATE MORE HEAT THAN A SMALLER SIZE RESISTOR.** The rate at which electric energy is converted to heat is expressed in **WATTS**.

Thus, every resistor has at least three ratings:

- (1) the resistance measured in ohms;
- (2) the tolerance measured in percent; and
- (3) the heat-dissipating ability measured in watts.

These ratings are separate and distinct. The resistance of a carbon resistor depends mainly on the composition of the mix; however, its heat-dissipating ability (wattage rating) depends mainly on its dimensions or physical size. This difference is illustrated in Figure 8 where the three resistors have exactly the same ohmic resistance, but their wattage rating varies with their size. The largest size resistor has the highest power rating and vice versa.

The tolerance rating depends on methods of manufacturing and selecting the resistors. For example, deposited film resistors are usually manufactured with close tolerance ratings ($\pm 1\%$ is typical).

For most electronic equipment, carbon type fixed resistors are available in 1/8 watt, 1/4 watt, 1/2 watt, 1 watt, and 2 watt sizes with resistance from about .1 ohm to about 22 megohms. Figure 8A shows the 2 watt size, 8B

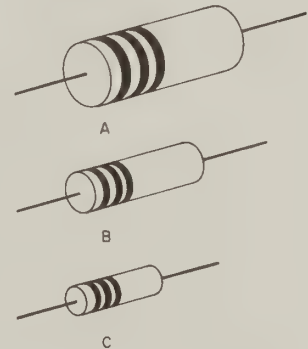


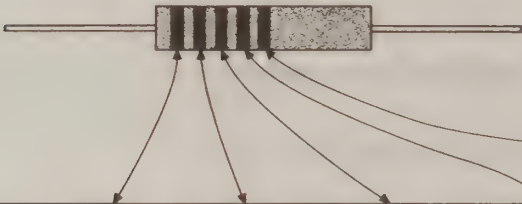
Figure
8

the 1 watt size and 8C the 1/2 watt size. General purpose wire-wound resistors similar to those shown in Figure 5 are manufactured in 5 watt, 10 watt, 20 watt and up to 200 watt sizes with resistances from about 1 ohm to about 250,000 ohms. WIRE-WOUND RESISTORS ARE OFTEN USED INSTEAD OF CARBON RESISTORS WHERE A LARGE AMOUNT OF ELECTRIC ENERGY MUST BE DISSIPATED AS HEAT.

RESISTOR COLOR CODE

Although the resistance value sometimes is printed on the resistor, another means of rapid identification is widely used. A standard color code is used in which ten colors represent the digits from 0 to 9. By placing the proper colors in a specified order on the body, the resistance value can be marked even on the smallest resistors.

AXIAL TYPE



COLOR	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5
	1ST NUMBER	2ND NUMBER	MULTIPLIER	TOLERANCE (PERCENT)	RELIABILITY (PERCENT)
BLACK	0	0	1		
BROWN	1	1	10		(M) 1.0
RED	2	2	100		(P) 0.1
ORANGE	3	3	1,000		(R) 0.01
YELLOW	4	4	10,000		(S) 0.001
GREEN	5	5	100,000		
BLUE	6	6	1,000,000		
VIOLET	7	7	10,000,000		
GRAY	8	8	100,000,000		
WHITE	9	9	1,000,000,000		
GOLD			0.1	5	
SILVER			0.01	10	
NONE				20	

Figure 9

The Electronic Industries Association (EIA) color code is given in Figure 9. Notice that each of the first ten colors, starting with black and ending with white, represents a digit from 0 to 9, as shown in the two columns labeled BAND 1 and BAND 2. In the BAND 3 column, the colors represent a multiplier. The first two numbers are multiplied by the multiplier to obtain the actual resistance.

Note that the multiplier for each color is the digit 1 followed by a number of zeros (no zeros to nine zeros) equal to the number (0 to 9) in the BAND 1 or BAND 2 column.

For resistance less than 10 ohms, either of two additional multipliers may be used, as shown in Figure 9. When band 3 is gold, the multiplier is 0.1. A silver 3rd band indicates a 0.01 multiplier. How these multipliers are used can best be shown by examples.

All of the colors in this code are in the form of bands, and the body color has no significance so far as the code is concerned. Checking Figure 9, the bands are closer to one end of the resistor than the other, and are read by starting with the band closest to an end.

As an example, assume the resistor at the top of Figure 9 has brown for the first band, black for the second band, and green for the third band. (Disregard the fourth and fifth bands for the moment.) By the chart, the resistance indicated is $10 \times 100,000$, or 1,000,000 ohms.

Following this plan, and checking with the table, any resistance from 0.01 ohm up to 99,000,000,000 ohms can be represented. The following examples further illustrate how the color code is used to determine resistance values.

BANDS			OHMS
1st	2nd	3rd	
Orange 3	White 9	Silver $\times 0.01$	.39
Blue 6	Gray 8	Gold $\times 0.1$	6.8
Brown 1	Green 5	Black $\times 1$	15
Green 5	Black 0	Brown $\times 10$	500
Violet 7	Green 5	Orange $\times 1000$	75,000
Yellow 4	Violet 7	Red $\times 100$	4700

CONDUCTORS AND RESISTORS

In some cases the colors of the bands may be alike; however, there will be at least three bands and the plan of determining the value of the resistance remains the same. For example:

BANDS			OHMS
1st	2nd	3rd	
Orange 3	Orange 3	Gold $\times 0.1$	3.3
Red 2	Red 2	Silver $\times 0.01$	.22
Yellow 4	Violet 7	Yellow $\times 10,000$	470,000

In the manufacture of fixed resistors, the resistance of resistors in a batch will vary somewhat due to slight differences in construction which cannot be avoided. When completed, the resistors are sorted and coded according to their accuracy. Their power or wattage rating has nothing to do with their tolerance.

To indicate their tolerance, a fourth color code band is provided on the resistor. As shown in Figure 9, gold indicates 5%, silver indicates 10%, and no fourth band indicates 20% tolerance.

Thus, a resistor that is color coded yellow, violet, red, silver is a 4700 ohm resistor with a tolerance of $\pm 10\%$. (The symbol $\pm$ means that the tolerance is both above (+) and below (—) the coded value.) Since 10% or .1 of 4700 ohms is 470 ohms, the resistor may actually have a resistance anywhere between 4230 ohms ($4700 - 470$) and 5170 ohms ($4700 + 470$).

The more accurate the resistance, the more expensive the resistor. For commercial electronic equipment, 20% or 10% tolerance is satisfactory. For high-quality equipment, 5% tolerance is common. For measuring instruments, it is customary to use "precision" resistors with a tolerance of 1% or less. When the tolerance is less than 5%, the resistance value and tolerance are usually printed on the resistor body and no color code is used.

Resistors used by the military are required to be tested for their ability to maintain their specified resistances at full rated power. This test is per-

formed by applying a voltage to a resistor, causing an electric current to flow. The current is adjusted to the level where the resistor's full wattage rating is achieved and maintained for 1000 hours. For example, the current through a 1 watt resistor is adjusted to the level that causes the 1 watt resistor to dissipate 1 watt of energy. At the end of this time a certain (very small) percentage of the resistors will have had their resistance values permanently changed above their tolerance rating. This percentage becomes the "failure rate" of this type of resistor. The lower the percentage of failure of the resistor, the more reliable it becomes. To indicate the Reliability Level, a fifth color code band is provided on the resistor. As shown in Figure 9, brown indicates 1.0%, red indicates 0.1%, orange indicates 0.01% and yellow indicates 0.001%. Some military applications express the Reliability Level in terms of letters: M (1.0%), P (0.1%), R (0.01%) and S (0.001%).

Some resistors with this fifth band are finding their way into commercial and industrial equipment. Modern manufacturing techniques are such that the normal reliability of carbon resistors is good enough for commercial and industrial applications. Therefore, for these applications, when the resistor has a reliability band, it is ignored.

A resistor chart, courtesy of Allen-Bradley Co., is included with this course. It shows the standard values of carbon resistors which are commercially available.

RESISTANCE DESIGNATIONS

Many of the resistors used in electronic equipment have resistance values in the thousands and millions of ohms. Instead of printing the complete number of the body of precision resistors or on resistor symbols in schematic diagrams, a shorter designation is used to save space.

The letter k or the prefix KILO is often used to indicate THOUSANDS of ohms, and the letter M or the prefix MEG is used to indicate MILLIONS of ohms. Therefore, a 10,000 ohm resistor is called a 10 kilohm resistor and is labeled 10 k Ω or 10K. A 4,700,000 ohm resistor is called a 4.7 megohm resistor and may be labeled 4.7 M Ω or 4.7M.

ADJUSTABLE RESISTORS

Although fixed resistors of all types find wide use in electronic equipment, circuit applications also require resistances which can be varied to act as

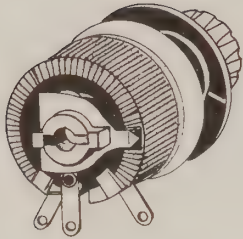
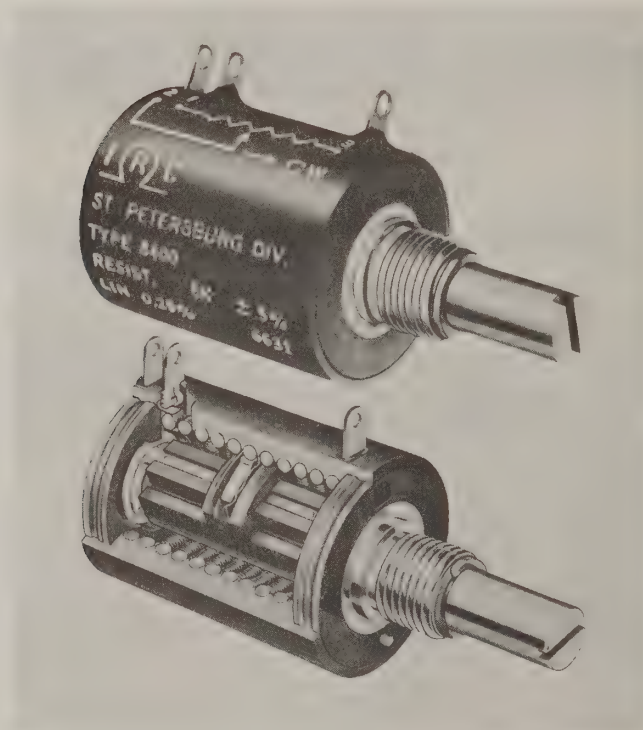


Figure
10

controls. One form of wire-wound adjustable control is shown in Figure 10. The resistance wire is wound on a flat strip that has been bent into a circular shape and mounted in an insulated housing. A shaft, with a contact arm fastened to the inner end, extends through the housing so that a knob or a dial can be attached to its outer end.

One end of the resistance element is attached to one of the end terminals. The other end of the resistance element is connected to the other end terminal. The contact arm is connected to the center terminal. As the shaft is rotated, the arm moves and the contact slides along the resistance wire. The position of the contact determines the resistance between the center terminal and either end terminal. An adjustable resistor with three external terminals connected into a circuit is a **POTENTIOMETER**, often called a **POT**. When the shaft is turned to move the sliding contact, the resistance between the movable contact and one outer terminal increases while the resistance between the movable contact and other outer terminal decreases.



A multiterminal variable resistor and a cutaway view of a variable resistor show how it is constructed. The resistance element is in the form of a coil. As the shaft is rotated, the wiper moves around the inside of the coiled resistance element.

Courtesy IRC Division of TRW Inc.

In certain applications, it is desirable to use only one end of the resistance element and the contact arm in the circuit. When only two terminals of the adjustable resistor are connected into a circuit, it is called a **RHEOSTAT**.

Figure 11A shows another method of adjustable resistor construction: a metal housing is placed over the resistance element. This arrangement encloses the resistance element and contact arm and protects them from damage and dust. Figure 11B shows one type of small potentiometer used in printed circuit board applications. The shaft is replaced by a wheel-like disc. The terminals are designed to fit into small holes in a printed circuit board.

Some adjustable resistors have carbon resistance elements similar to those of carbon fixed resistors. The external appearance of a carbon control may be very similar to that of a wire-wound control. The resistance element of a carbon unit can be a strip of insulating material coated with a carbon mix instead of wound with resistance wire. Carbon controls usually have higher resistance and less heat-dissipating ability (lower wattage ratings) than wire-wound controls.

To save space and reduce the number of controls, it is common practice to install a switch on the back of some adjustable resistors as shown in Figure 12. The switch is electrically separate from the potentiometer, but both are controlled mechanically by one shaft. A common example of this arrangement is found in radio and TV receivers where the set is turned on or off by the same knob that is rotated to vary the sound volume.

In certain electronic circuits, where it is desirable to vary two resistances in some fixed relation to each other, a ganged control shown in Figure 13 is used. Electrically, the control consists of two entirely separate potentiometers, similar to the one shown in Figure 11. Mechanically, the same shaft controls the position of both contact arms. Thus, the controls can be connected into separate electric circuits but are varied simultaneously.

A modification of this assembly is a dual control in which the two potentiometers may be varied independently by means of a two-piece knob. In this type of assembly, the shaft of the front control is a hollow tube through which the shaft of the rear control extends. Assemblies of this type, called concentric controls, are found in a wide variety of electronic equipment, the most familiar of which is the television receiver. Here a concentric control with one knob inside of another knob may be used to vary the picture contrast and the sound volume independently.

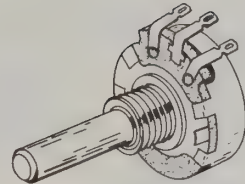


Figure
11A



Figure
11B

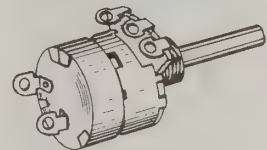


Figure
12

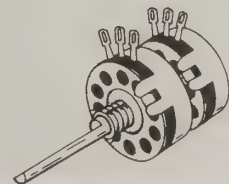


Figure
13

CONDUCTORS AND RESISTORS

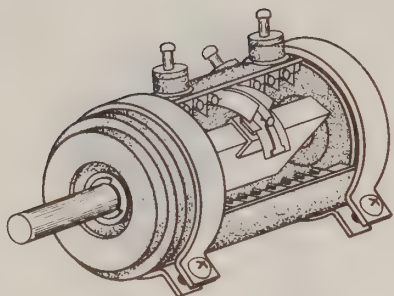
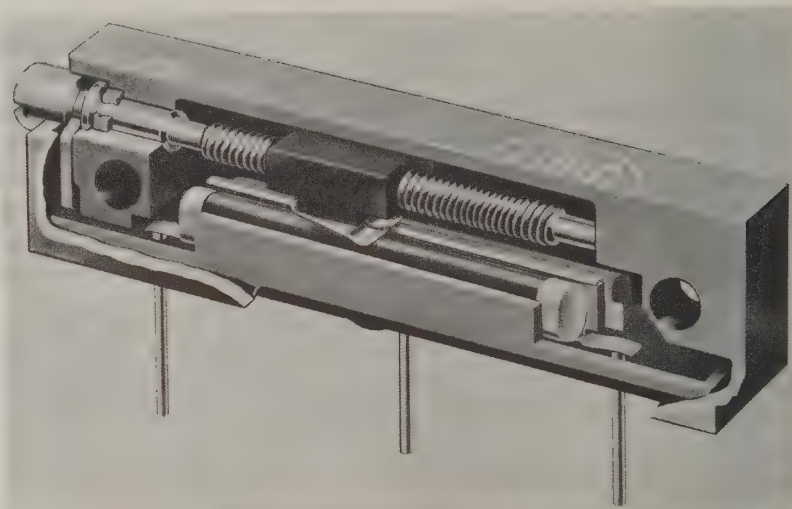


Figure
14A



Courtesy IRC Division of TRW INC
Figure 14B



Courtesy IRC Division of TRW INC
Figure 14C

In all of the controls previously described, the amount of shaft rotation is less than one full turn (about 300°). This limits the accuracy of the setting of the controls. To obtain a higher degree of precision, the resistance element can be wound into a spiral so that several turns of the movable contact are required to go from one end to another. A precision potentiometer of this type is shown in the cutaway view of Figure 14A. Generally, 5, 10 or 15 turns are required for a full change in resistance. Figure 14B shows a cutaway view of a precision potentiometer used in printed circuit board applications. Figure 14C shows another configuration of the precision printed circuit potentiometer.

SPECIAL PURPOSE RESISTORS

Besides the common variety of fixed and adjustable resistors, there are many special purpose resistors. These are resistors which have special characteristics and are used only in specific applications.

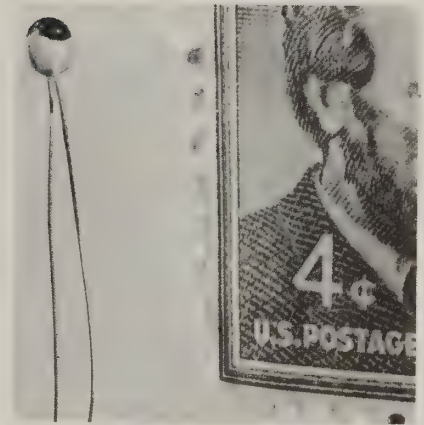
One type of widely used temperature-sensitive, special purpose resistor is the **THERMISTOR**. The thermistor is designed to have a definite change of resistance when its temperature changes. The change of resistance with changes of temperature is referred to as the temperature coefficient of the thermistor. If the resistance increases with an increase of temperature, the thermistor has a positive temperature coefficient; a decrease of resistance with an increase of temperature is specified as a negative temperature coefficient.

One type of widely used light-sensitive, special purpose resistor is the **PHOTOCONDUCTIVE CELL**. The resistance of most photoconductive cells varies inversely as the intensity of light falls upon the cell. This means that when the light intensity increases, the cell resistance decreases. When the light intensity decreases, the cell resistance increases.

Other special purpose resistors are designed to be sensitive to such things as pressure, strain and humidity.

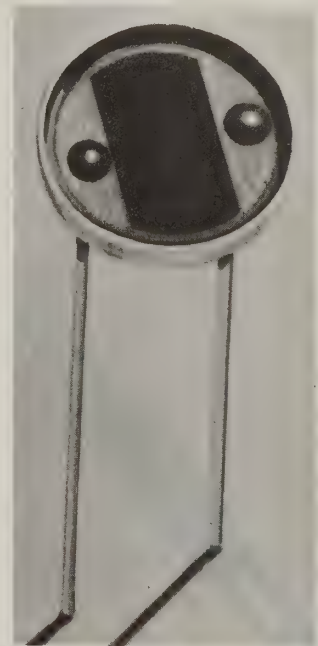
FUSES

Whenever an electric current passes through a conductor or component of a circuit, it produces a certain amount of heat. If this unwanted heat is excessive, it can result in permanent damage to the circuit components. To



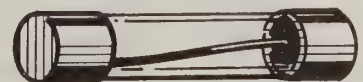
A precision thermistor is a small, highly heat-sensitive special resistor.

Courtesy Yellow Springs Instrument Co.



A photoconductive cell is a light-sensitive special resistor.

Courtesy Fairchild Instrumentation Co.



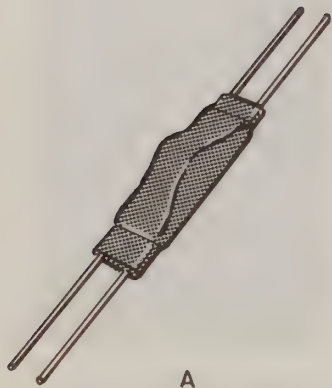
The fuse is used as a predictable safety device in electric and electronic circuits.

prevent this from happening, a special conductor, called a fuse, is used in the circuit. A **FUSE** is a predictable protective device used in electric and electronic circuits. When the current rating specified on the fuse is exceeded, a wire or solder spring device melts and opens the circuit. This action protects the components in a circuit from damage due to excessive heat.

INSULATORS

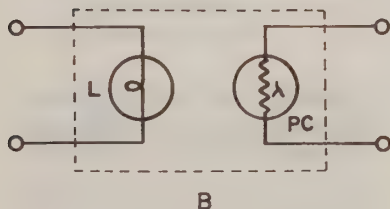
In the construction of electronic circuits, it is just as important to have insulators as it is to have conductors and resistors. A characteristic of electricity is that it will always take the **EASIEST POSSIBLE PATH**. To carry electric energy from a source to a load, we use conductors to provide an easy path. Precautions must be taken to prevent unwanted paths from occurring.

A way to accomplish this would be to separate all conductors. The possibility that the conductors will touch any other object would now be eliminated. In this case, the air between the conductors is the insulator. In many situations this is not a practical solution, and therefore it becomes necessary to use other insulating materials to prevent the undesired electric paths. A plastic insulating material is often placed around the conductor. A common example of this method of insulating conductors is found in hookup wire. A number of these wires may be bunched together. The plastic insulation prevents any undesirable electric paths from occurring.



A

There are many types of insulators. However, they all have one thing in common: the atoms making up the insulating materials all have very few free electrons. Therefore, it is difficult to force an electric current through them. Some common insulators are glass, mica, ceramic, paper, air, plastic, rubber, fiber glass and enamel. Insulators are used to support the wires making up electric power lines. Insulating material is often used to coat electrical and electronic components to keep electric current in the desired paths.



B

Figure
15

OPTICAL COUPLERS

The optical coupler shown in Figure 15A has a photoconductive cell and a light source encapsulated within an electrically nonconductive opaque plastic compound to prevent the entry of unwanted light. Either an ac or dc signal can be applied to the lamp which is used as the input for the optical coupler. The optical coupler is shown in the schematic diagram of Figure 15B.

The light output of the lamp controls the resistance of the photocell. When no voltage is applied to the lamp, it is dark and the photocell resistance is about 10,000,000 ohms. As the voltage to the lamp is increased, it glows more brightly. This light shines on the photocell and reduces its resistance. When the maximum rated voltage is applied to the lamp, its light reduces the photocell resistance to about 500 ohms.

The lamp voltage is normally controlled by one part of an electrical system and the photocell is connected in another part of the system. Therefore, the changing lamp voltage can be made to control the other part of the system as the changing lamp light changes the photocell resistance.

CONNECTORS AND CONNECTIONS

Since wire is used mainly to provide the desired path between the source of electric energy and the device that utilizes it, the wire must be connected to both. Immediately, the problem arises of providing a low-resistance connection between the wire and the source, as well as between the wire and the load.

A good electric connection can be made by tightly twisting together two clean copper wires. However, even though the wires remain tightly twisted, their outer surfaces may corrode or oxidize (the pure metal combines with oxygen in the air). In a comparatively short time, a connection of this kind can develop an increase of resistance due to corrosion or oxidation that may prevent the complete circuit from operating properly. To prevent this condition, most permanent connections in electronic equipment are soldered.

Soldering

Solder is an alloy of two or more metals (mainly lead and tin) and appears as a soft, thin, silver-white metal which melts at relatively low temperatures. When in molten form, the solder covers or "tins" many other metals. To make a soldered connection, the wires or other metal parts are cleaned and held in contact with each other. The parts are then heated, usually by means of a soldering iron, until they are hot enough to melt the solder. The solder applied to the heated parts melts and flows between the heated parts, coating their outer surfaces.

When the solder cools and hardens, it forms a solid, metallic, low-resistance path between the parts. Also by covering the outer surfaces, corrosion or

oxidation, which occurs when the surfaces are exposed to the air, is prevented. By providing what amounts to a solid metal contact, the solder provides a permanent, low-resistance connection or joint.

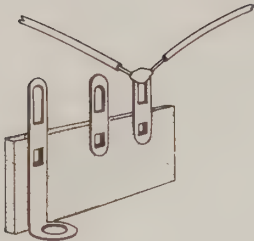


Figure
16

THE MAIN PURPOSE OF SOLDERING A CONNECTION IS TO PROVIDE A LOW-RESISTANCE ELECTRICAL CONNECTION, not to make a strong physical connection. Figure 16 shows how two wires are soldered to a terminal.

Wrap-Around Connections

Although soldering is still the most common method of making connections, solderless wire-wrapping techniques are considered to be a reliable connection method. The method shown in Figure 17 uses a terminal with at least one square corner. By tightly wrapping the wire four or five times around the terminal, the corners of the terminal pierce the wire enough to form a good metal-to-metal contact.

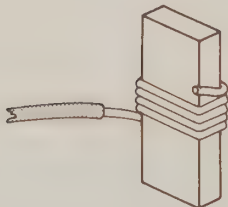


Figure
17

Tension in the wire and twist in the terminal allow enough pressure on the joint to provide a permanent, low-resistance contact. Special wire-wrapping tools are required when using this technique. If it becomes necessary to rewrap a connection of this type without special tools, the connection should be soldered.

Jacks and Plugs

Many electronic devices require the frequent connection and removal of external wires. Numerous types of connectors have been developed for this purpose. They are constructed to accommodate one or more separate wires, as shown in Figure 18.

Figure 18A shows a metal tip or **PLUG** which, when used, has a single conductor connected in its larger, hollow end. The corresponding receptacle or **JACK** (Figure 18B) has a central opening to accommodate the end of the plug. The jack body has external threads and a nut for permanent mounting on a panel of an electronic device. Connections are made to the lug at the other end of the jack. Thus, by inserting the plug into the jack, the external wire can be connected to the internal wiring of the device. By removing the plug from the jack, the external wire is disconnected from the internal wiring.

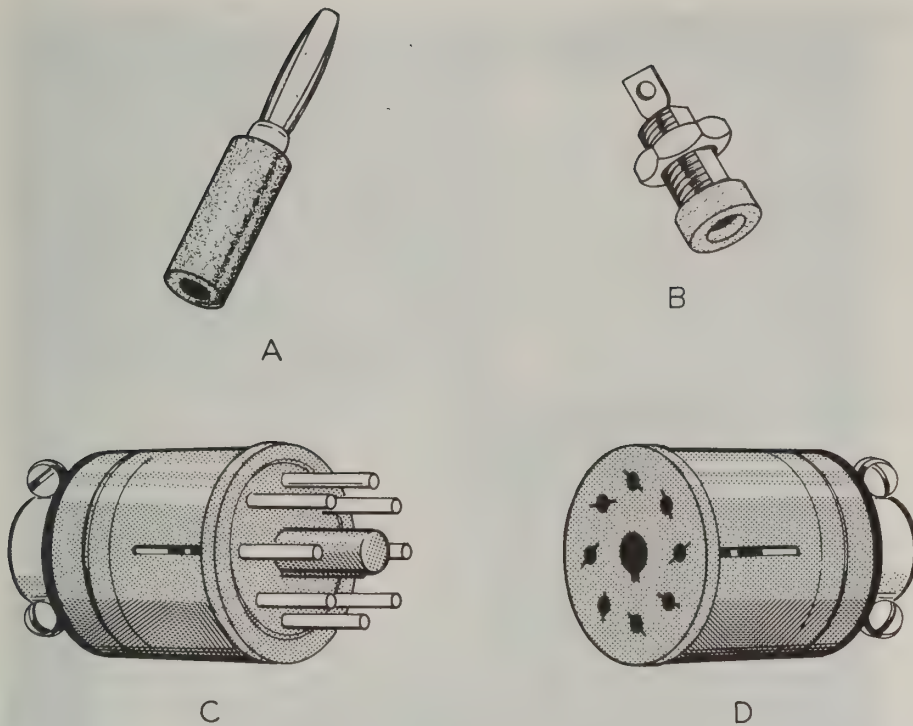


Figure 18

When more than one wire must be connected or disconnected at the same time, special types of multiple contact connectors may be used. Figures 18C and 18D show an eight-contact plug and jack, respectively. The plug and receptacle are keyed so they fit together only one way. The plugs of Figures 18A and C are also called male connectors and those of Figures 18B and D are called female connectors.

The plug-in printed circuit boards shown in Figure 19 are used when entire circuits are to be removed and/or replaced quickly. They are found in many commercial and industrial pieces of equipment. A modern electronic telephone exchange may use many of these plug-in printed circuit boards. This allows the telephone exchange to continue to function properly in the event of a component (or circuit) failure. When a failure is detected, the suspected plug-in printed circuit board is removed and replaced with another plug-in printed circuit board containing the same circuitry.

There are various other types of connectors used in the electronics industry. All of them, however, are for the purpose of providing good electrical connections which can be readily disconnected.

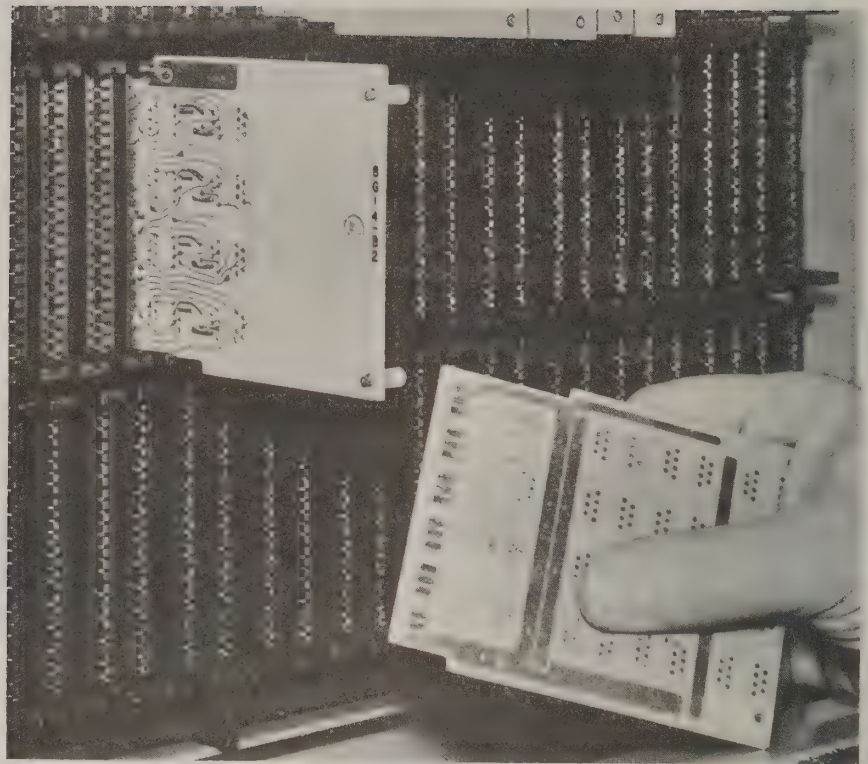


Figure 19

Courtesy RCA EDP

SUMMARY

All materials offer some resistance to the passage of an electric current. The amount of this resistance determines whether the material is classified as a conductor, resistor or insulator. A material with low resistance has a high conductance. Conductors, such as copper wires, offer very little resistance. Insulators, such as glass or plastic, offer a great amount of resistance. Resistors are usually designed to offer a specific amount of resistance.

All three types of materials are vitally important to the successful use of electric circuits. Conductors and insulators force the electric current to follow only desired paths, while resistors help to control the amount of current in an electric circuit.

The larger the diameter of a wire, the greater its cross-sectional area. The greater the cross-sectional area, the less resistance the wire offers to current, and the more current it can safely carry.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

ADJUSTABLE RESISTORS**SPECIAL PURPOSE RESISTORS****FUSES****INSULATORS****OPTICAL COUPLERS****CONNECTORS AND CONNECTIONS****SOLDERING****WRAP-AROUND CONNECTIONS****JACKS AND PLUGS**

35. When an adjustable resistor is used as a rheostat, how many of its terminals are connected into a circuit?
36. What is the basic difference between a rheostat and a potentiometer?
37. Compared to wire-wound controls, carbon controls usually have (a) lower resistance rating, (b) less heat-dissipating ability.
38. A concentric control is one in which the two control elements are (a) ganged together and are varied simultaneously, (b) varied independently of each other.
39. A special resistor is constructed so its resistance decreases as it becomes warmer. Does this resistor have a negative or positive temperature coefficient?

- 40. The resistance of a photoconductive cell changes with changes of (a) temperature, (b) humidity, (c) light intensity.
- 41. The purpose of an insulator is to (a) prevent undesired paths for electric current, (b) provide added physical strength for conductors, (c) limit the current through the load.
- 42. What is the main reason for soldering a connection?
- 43. In some electronic equipment, the wrap-around connection technique is employed. When replacing a component in this equipment, what connection technique would you use?
- 44. Why are plugs and sockets used for some external electric connections?

Resistors are manufactured in fixed and adjustable forms. They are usually wire-wound, film type, or carbon mix type. A standard color code (EIA) is often used to identify the resistance value of a carbon resistor.

Resistors are formed in microminiature or integrated circuits by diffusing a substance such as aluminum into the basic circuit material. The resistance of a resistor depends on the length and composition of the resistance material.

The three important ratings of a resistor are its resistance in ohms, its tolerance in percent, and its heat-dissipating ability (wattage) in watts.

APPENDIX A

CONDUCTOR RESISTANCE

The resistance of a conductor can be expressed with the following formula:

$$R = \frac{\rho l}{d^2}$$

where: R = conductor resistance

ρ = specific resistance

l = conductor length in feet.

d^2 = cross-sectional area in circular mils.

The specific resistance is the resistance in ohms of a one foot length of the material with an area of one circular mil. The table below lists the specific resistance of several common conductors.

MATERIAL	SPECIFIC RESISTANCE
Silver	9.75
Copper	10.55
Aluminum	17.30
Nickel	53.00
Iron	61.00
Lead	115.00
Nichrome	660.00

To illustrate the use of the formula, suppose we have a length of copper wire 10 feet long with a cross-sectional area of 5 circular mils. The resistance of this wire would be:

$$R = \frac{\rho l}{d^2} = \frac{10.55 \times 10}{5}$$

$$R = \frac{105.5}{5} = 21.1 \text{ ohms.}$$

APPENDIX B

COPPER WIRE TABLE

Since most wires are cylindrical and quite small, it is rather inconvenient to measure their diameters in fractions of an inch and the cross-sectional areas in square inches. Therefore, much smaller units of measure are employed.

The unit for the measurement of wire diameters is the MIL which is equal to one one-thousandth of an inch. To change inches to mils, merely multiply the number of inches by 1000. To change mils to inches, divide the number of mils by 1000.

The cross-sectional area of a wire affects its resistance or ability to carry current. The smaller the area, the greater the resistance of a conductor. To simplify the computation of cross-sectional areas of wires, the unit of measure is the CIRCULAR MIL, which is equal to the area of a circle one mil in diameter. Thus, the circular mil cross-sectional area of a wire is equal to the square of its mil diameter. For example, a wire having a 1 mil diameter has a cross-sectional area of 1×1 , or 1 circular mil, and a 5 mil diameter wire has a cross-sectional area of 5×5 , or 25 circular mils.

Some of the characteristics of different sizes of solid wire are shown in chart form in the accompanying Copper Wire Table. The gauge numbers start at 0000, read as "four oh," and continue down through 000, 00, 0 and 1 to 40.

The second column from the left, labeled Diam. in Mils, lists the actual diameter of each gauge number wire in mils or thousandths of an inch.

Reading across, a No. 0000 wire has a diameter of 460.0 mils, which is equal to .460 inch. Comparing column one with column two, notice that the mil diameters decrease as the gauge numbers increase.

The third column, Area in Circular Mils, tabulates the squares of the mil diameters.

The fourth column lists the Resistance of Pure Copper at 68° F. in ohms per 1000 Ft. Checking gauge No. 28, a thousand feet of this copper wire has 64.9 ohms of resistance.

The fifth column shows the number of Feet per Ohm. For gauge No. 20, 98.5 feet of the wire has a resistance of 1 ohm.

To determine the wire size, a technician uses a "wire gauge." One popular gauge is circular in shape and has a series of slots placed around the outside edge. These are numbered the same as the wire sizes and, of course, are of the proper size. To measure a piece of wire with a gauge of this type, find the smallest slot the wire will enter. The number of this slot is the size of the wire.

In electronic equipment, No. 22 is a typical size employed for the electric conductors. Checking the table, No. 22 is 25.35 mils in diameter, has an area of 642.6 circular mils, and 1000 ft. of this wire has a resistance of 16.14

CONDUCTORS AND RESISTORS

ohms. Since the usual length of a single "hookup" wire is less than 10 ft., negligible resistance is added by the wiring in an electronic device.

The wire size for a specific application usually depends upon several factors such as material, allowable temperature rise for a given type of insulation and the current-carrying capacity of the wire, to name a few. For these reasons, complete details as to the conditions of operation of the equipment must be known before the proper wire size can be selected. Therefore, random selection of a wire size for an application should not be made.

COPPER WIRE TABLE

Gauge No.	Diam. in Mils	Area in Circular Mils	Resistance of Pure Copper in Ohms at 68° F.	
			Ohms per 1000 Ft.	Feet per Ohm
0000	460.0	211600.	.04901	20400.
000	409.6	167800.	.06180	16180.
00	364.8	133100.	.07793	12830.
0	324.9	105500.	.09827	10180.
1	289.3	83690.	.1239	8070.
2	257.6	66370.	.1563	6400.
3	229.4	52640.	.1970	5075.
4	204.3	41740.	.2485	4025.
5	181.9	33100.	.3133	3192.
6	162.0	26250.	.3951	2531.
7	144.3	20820.	.4982	2007.
8	128.5	16510.	.6282	1592.
9	114.4	13090.	.7921	1262.
10	101.9	10380.	.9989	1001.
11	90.74	8234.	1.260	794.
12	80.81	6530.	1.588	629.
13	71.96	5178.	2.003	499.3
14	64.08	4107.	2.525	396.0
15	57.07	3257.	3.184	314.0
16	50.82	2583.	4.016	249.0
17	45.26	2048.	5.064	197.5
18	40.30	1624.	6.385	156.6
19	35.89	1288.	8.051	124.2
20	31.96	1022.	10.15	98.50
21	28.46	810.1	12.80	78.11
22	25.35	642.6	16.14	61.95
23	22.57	509.5	20.36	49.13
24	20.10	404.0	25.67	38.96
25	17.90	320.4	32.37	30.90
26	15.94	254.1	40.81	24.50
27	14.20	201.5	51.47	19.43
28	12.64	159.8	64.90	15.41
29	11.26	126.7	81.83	12.22
30	10.03	100.5	103.2	9.691
31	8.928	79.70	130.1	7.685
32	7.950	63.21	164.1	6.095
33	7.080	50.13	206.9	4.833
34	6.305	39.75	260.9	3.833
35	5.615	31.52	329.0	3.040
36	5.000	25.00	414.8	2.411
37	4.453	19.83	523.1	1.912
38	3.965	15.72	659.6	1.516
39	3.531	12.47	831.8	1.202
40	3.145	9.89	1049.	.9534

IMPORTANT DEFINITIONS

CARBON RESISTOR — A resistor in which the resistance element is composed of a carbon or graphite compound.

CIRCULAR MIL — The unit of measure for wire cross-sectional area. One circular mil is the area of a circle of one mil diameter (.001 inch).

CONDUCTANCE — The ease with which electric current flows in a circuit. The reciprocal of resistance.

CONDUCTOR — A material that readily permits an electric current, or flow of electrons. A material in which the atoms contain many free electrons.

DEPOSITED FILM RESISTOR — A resistor which has a thin coating of conducting material deposited on the surface of a small glass or ceramic rod.

DIFFUSED RESISTOR — A resistor produced by diffusing impurities such as aluminum into silicon material such as that used in integrated circuits.

FIXED RESISTOR — A resistor having a definite resistance and designed to maintain this value with practically no change under normal operating conditions.

FUSE — A predictable safety device used in electrical and electronic circuits to protect the components from damage due to excessive heat.

HOOKUP WIRE — Copper wire, usually with a layer of insulation, used to complete the circuits in electronic equipment. The wire may be "tinned" before the insulation is added and can be either solid or stranded.

INSULATOR — A material which offers extremely high resistance to electric current; for most purposes, one that blocks the flow of electrons.

JACK — A device which receives a plug and provides electric contact between each prong on the plug and each receptacle on itself.

IMPORTANT DEFINITIONS (Continued)

MHO — A basic unit of conductance. THE SIEMENS has been adopted as a replacement for this unit.

MIL — Unit of measure for wire diameter; 1 mil. is .001 inch, or 1000 mils equal 1 inch.

OHM — The basic unit of measurement of resistance to electric current.

PHOTOCONDUCTIVE CELL — A special purpose resistor whose resistance changes with changes of light intensity.

PLUG — A device with one or more conducting prongs, inserted into a jack to provide electrical connections.

POT — Abbreviation for POTENTIOMETER.

POTENTIOMETER — An adjustable resistance with three external terminals.

RESISTANCE (R) — The physical property of a device which opposes current in an electric circuit.

RESISTANCE WIRE — Wire made of metal alloys to present certain desired resistance characteristics.

RESISTOR — A component designed to offer a specific resistance or opposition to current.

RHEOSTAT — An adjustable resistance in which two external terminals, corresponding to one fixed contact and one movable contact, are used.

SHORT CIRCUIT — A condition that provides an undesired path for electric current.

IMPORTANT DEFINITIONS (Continued)

SIEMENS — A basic unit of conductance. This unit has been adopted as a replacement for the MHO.

THERMISTOR — A special purpose resistor whose resistance changes with changes of temperature.

TOLERANCE — The amount that the actual value of a component (such as the resistance of a resistor) may differ from its marked value. Usually expressed as percentage of the marked value.

WATTAGE RATING — An indication of how much heat a component such as a resistor can safely dissipate. The larger the physical size of a resistor, the higher the wattage rating and the more energy it can safely dissipate as heat.

WIRE-WOUND RESISTOR — A resistor in which the element consists of a resistance wire wound on a ceramic tube or other insulating material. It is used mainly in high-power circuits.

ESSENTIAL SYMBOLS AND EQUATIONS

R Resistance in ohms

G Conductance in siemens or mhos

$$G = \frac{1}{R} \quad (1)$$

PRACTICE EXERCISE SOLUTIONS

1. current
2. (b) ohm.—The volt is related to electric pressure; the ampere to electric current.
3. (b) a movement of more electrons.
4. (b) the current doubles.—The resistance does not depend on voltage or current.
5. (c) the conductance is decreased.—An increase of resistance does not affect the source voltage, and actually causes the current to decrease.
6. True
7. (b) Mercury.—The resistance of mercury is 55 times that of copper and silver is .95 that of copper.
8. Solid wire is easy to work with. It is also economical.
9. Greater flexibility.
10. Stranded.—The greater flexibility of stranded wire will help to prevent it from becoming damaged by frequent movement.
11. 6400 circular mils.—The area is equal to the diameter squared ($80 \times 80 = 6400$).
12. (c) $1/9$ the resistance of a 1 mil wire.—A 3 mil wire has 9 times the cross-sectional area of a 1 mil wire; thus, it has $1/9$ the resistance. This assumes that both wires are made of the same material.
13. (c) as the circular mil area increases.—A decrease of diameter, or an increase of length, causes the resistance of copper wire to increase.

PRACTICE EXERCISE SOLUTIONS (Continued)

14. False—Whenever electricity passes through a conductor, it produces a certain amount of heat. The resistance of a conductor changes with temperature change.
15. True—Copper wire is the most commonly used type of wire because of its relatively low cost and its low resistivity.
16. No. 20 wire is larger, having a diameter of 31.96 mils compared to only 3.145 mils for No. 40 wire.
17. 12.77 ohms.—No. 18 copper wire has a resistance of 6.385 ohms per 1000 feet. Thus, 2000 feet of wire would have a resistance of 2×6.385 ohms, or 12.77 ohms.
18. False—Printed circuit wiring is ideal for mass production of transistor radios, computer circuits and many other types of electronic equipment.
19. True—Resistors do have other uses. However, the most important use is to control current.
20. (c) resistance wire.
21. False—Carbon resistors are made of a mix consisting of carbon and a binder such as bakelite.
22. conductive
23. diffused resistor
24. False—The wider the current path between the end points of a diffused resistor, the smaller the resistance. Thus, by doubling the width of the current path, the resistance would be halved.
25. The type of material, its cross-sectional area and its length.

PRACTICE EXERCISE SOLUTIONS (Continued)

26. Resistance, tolerance and heat-dissipating ability.
27. The resistor which is 1" long since it has more surface area.
28. The color code enables the rapid identification of resistance values.
29. 5600 ohms.
30. 47,000 ohms.
31. 33,000 ohms.
32. 27,000 ohms and 680 ohms.—If you happened to get 18,000,000 ohms for that second resistor, you overlooked the fact that the color bands always start with the one closest to the end of the resistor body.
33. 36,300 ohms ($33,000 + 3,300$) is the maximum resistance and 29,700 ohms ($33,000 - 3,300$) is the minimum resistance.
- 34.

Value of Resistor			Value of Resistor		
Diagram Number	In Ohms	in $k\Omega$'s or Meg Ω 's	Diagram Number	In Ohms	in $k\Omega$'s or Meg Ω 's
1	68,000	68 $k\Omega$	11	100,000	100 $k\Omega$
2	680,000	680 $k\Omega$	12	330	—
3	2,200	2.2 $k\Omega$	13	330,000	330 $k\Omega$
4	470	—	14	220,000	220 $k\Omega$
5	100	—	15	3,300,000	3.3 M Ω
6	68	—	16	4,700	4.7 $k\Omega$
7	10,000,000	10 M Ω	17	220	—
8	470,000	470 $k\Omega$	18	3,300	3.3 $k\Omega$
9	1,500	1.5 $k\Omega$	19	4,700,000	4.7 M Ω
10	47,000	47 $k\Omega$	20	6,800	6.8 $k\Omega$

PRACTICE EXERCISE SOLUTIONS (Continued)

35. Two.—Even though the adjustable resistor may have three terminals, only two terminals (one end and the slider) are connected into a circuit when it is used as a rheostat.
36. A rheostat uses two terminals (one end and the slider) and a potentiometer uses all three terminals (both ends and the slider).
37. (b) less heat-dissipating ability.
38. (b) varied independently of each other.
39. A negative temperature coefficient.
40. (c) light intensity.
41. (a) prevent undesired paths for electric current.
42. To make a permanent, low-resistance electrical connection.
43. Unless you have the special wrapping tools for this type of connection, it would be best to solder the connection.
44. Speed and convenience in making good electric connections which can be easily disconnected.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE
1004A

Example:

A	☐
B	☒
C	☐
D	☐

A pencil is a device used for

A. digging ditches. B. writing. C. chopping wood. D. cooking.

1. A ☐ **Insulation is used on wires to**
 B ☐ (A) prevent short circuits. (B) reduce their cost. (C) increase their strength. (D) reduce their resistance.
 C ☐
 D ☐
2. A ☐ **What three important ratings do all resistors have?**
 B ☐ (A) Resistance, tolerance and heat-dissipating ability. (B) Size, shape and wattage. (C) Length, diameter and color. (D) Wattage, length and voltage.
 C ☐
 D ☐
3. A ☐ **When two or more conductors are connected, the main purpose of soldering the joint is to**
 B ☐ (A) provide a low-resistance connection. (B) make a high-resistance connection. (C) make a strong physical connection. (D) permit rapid disconnection of the conductors.
 C ☐
 D ☐
4. A ☐ **The band nearest one end of a resistor is color coded brown, the second band is black, the third band is orange and the fourth band is silver. Its resistance and tolerance rating are:**
 B ☐ (A) 300 ohms $\pm$ 10%. (B) 10,000 ohms $\pm$ 10%. (C) 300 ohms $\pm$ 5%. (D) 10,000 ohms $\pm$ 5%.
 C ☐
 D ☐
5. A ☐ **The heat-dissipating ability (wattage rating) of a carbon resistor depends mainly on its**
 B ☐ (A) dimensions or physical size. (B) conductivity. (C) electric resistance. (D) tolerance rating.
 C ☐
 D ☐
6. A ☐ **Wire-wound resistors are often used instead of carbon resistors**
 B ☐ (A) where a resistance of greater than 10 megohms is required. (B) in low-power circuits. (C) where a large amount of electric energy must be dissipated as heat. (D) to decrease the total resistance.
 C ☐
 D ☐
7. A ☐ **Which of the following factors affects the resistance of a wire?**
 B ☐ (A) The direction of electron flow. (B) The polarity of the source voltage. (C) The type of insulation. (D) The material of which the wire is made.
 C ☐
 D ☐
8. A ☐ **A 20-ohm resistor has a tolerance of 10%. Its actual value should be between**
 B ☐ (A) 18 and 22 ohms. (B) 20 and 24 ohms. (C) 16 and 20 ohms. (D) 5 and 10 ohms.
 C ☐
 D ☐
9. A ☐ **Which of the following is true of a LARGER diameter wire as compared to a wire with a smaller diameter?**
 B ☐ (A) The larger diameter wire offers MORE RESISTANCE to current. (B) The larger diameter wire has a SMALLER cross-sectional area. (C) The larger diameter wire offers LESS RESISTANCE to current. (D) The larger diameter wire can carry LESS CURRENT.
 C ☐
 D ☐
10. A ☐ **A precision resistor which is marked 5 k Ω $\pm$ 1% has a**
 B ☐ (A) minimum resistance of 4,950,000 ohms. (B) maximum resistance of 505 ohms. (C) minimum resistance of 4950 ohms. (D) maximum resistance of 5,500,000 ohms.
 C ☐
 D ☐

VOLTAGE, CURRENT AND RESISTANCE

1007



Georg Simon Ohm (1787-1854) discovered the fundamental relationship between voltage, current and resistance. Ohm's Law, a simple statement of great electrical truth, ranks in importance with the law of gravitation.

Courtesy Ohmite Manufacturing Co.

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Three things are good in little measure and evil in large; yeast, salt and hesitation.
—Talmud

VOLTAGE, CURRENT AND RESISTANCE

The key factors in the progress of electronics have been the ability to identify the basic electric properties and to determine how these properties are related to each other. Before this relationship was discovered, there was no way of predicting how the current would be affected if the voltage or resistance changed. To get the desired results from a circuit, different parts had to be tried until the right combination was found.

Electronics was raised above this “tinkering” state largely through the work of Dr. Georg Simon Ohm, a German physicist of the 19th century. Dr. Ohm learned that voltage, current and resistance are related to each other in a definite way. After years of careful tests, he set forth a law that governs the operation of all circuits.

The use of standard units also has aided the progress of electronics. In the early days of electricity, number values were not used; measurements were impossible, and there was no way to describe exactly what happened when some change was made in the circuit. Today, we have a great advantage. We can measure the voltage, current or resistance in standard units, and study these values to learn just what is going on in the circuit.

STANDARD UNITS

The standard units are named in honor of the men who have contributed so much to the progress of electronics. The basic unit of current, or rate of electron flow, is the ampere. This unit is named in honor of a French physicist, André Ampère, who discovered certain relationships between electricity and magnetism.

The basic unit of electric pressure, or voltage, is the volt. This unit is named after Allesandro Volta, an Italian physicist, who is credited with developing the voltaic cell or battery. The basic unit of resistance, or opposition to electron flow, is the ohm, named for Dr. Ohm, who discovered the relationship between voltage, current and resistance.

The properties represented by these three units are related. Therefore, a convenient way to identify the standard units of voltage, current and resistance is to compare them to each other.

VOLT—The electric pressure required to produce one ampere of current in a circuit having one ohm of resistance.

AMPERE—The current that exists when a pressure of one volt is applied to a circuit having one ohm of resistance.

OHM—The resistance required to limit the current to one ampere when a pressure of one volt is applied.

To help you become familiar with the units and the quantities they represent, the chart of Figure 1 shows the letter symbol, the standard unit, and the standard abbreviation (unit symbol) for each of the three basic quantities. Thus, the chart indicates that the electric pressure (E) is expressed in volts (V); the rate of electron flow, or current (I), is measured in amperes (A); and the resistance (R) to electron flow is measured in ohms (Ω). The symbol (Ω) is the Greek capital letter Omega.

LETTER SYMBOL	STANDARD UNIT	UNIT SYMBOL
E	VOLT	V
I	AMPERE	A
R	OHM	Ω

Figure
1

OHM'S LAW

Through his experiments, Dr. Ohm learned that the current in a circuit can be varied by changing either the voltage applied to the circuit or the amount of circuit resistance. Furthermore, he found that the current changes in exactly the same proportion as the change in voltage or resistance. However, a change in voltage and a change in resistance have exactly opposite effects on the current. IF THE VOLTAGE INCREASES, THE CURRENT INCREASES, but IF THE RESISTANCE INCREASES, THE CURRENT DECREASES. This important relationship, the basis of electron circuit action, is called **OHM'S LAW**.

If we stop to think about this relationship, we find that it is a very logical one. The voltage is the electric pressure that causes the flow of electrons, and if we apply more pressure, we expect the current to increase. Using the same reasoning, the resistance is the opposition to the electron flow, and if there is a greater amount of opposition, we expect the current to decrease.

This relationship is often compared to the relationship between pressure, flow and opposition in a water system. If a greater pressure is applied to a given water system, more gallons of water will flow through the system in a given period of time. However, if a greater opposition is presented to the flow of water, there will be fewer gallons per unit of time flowing through the system.

By using Ohm's Law, we can predict what is going to happen in a circuit when a certain combination of values is used. To illustrate the relationship, we can assume sets of values for the circuit shown in Figure 2, and see how Ohm's Law applies. To begin with, let's study just two quantities at a time.

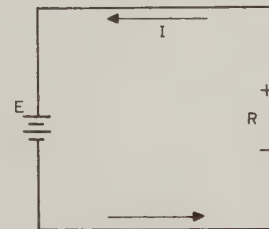


Figure
2

Voltage and Current

In the circuit shown in Figure 2, assume that the resistance R is 1 ohm. According to the definitions of the standard units, a battery voltage E of 1 volt produces a current I of 1 ampere in this circuit. If the electric pressure E is increased to 2 volts, the current doubles, as long as the resistance remains the same. With the same 1 ohm of resistance, the current increases to 20 amperes if the voltage is increased to 20 volts. In fact, increasing or decreasing the voltage by any amount causes the current to vary by that same amount, as long as the resistance is kept at the same value. This relationship between voltage and current is referred to as a **DIRECT PROPORTION**, since any change in voltage causes the current to change in exactly the same manner.

Based on the circuit shown in Figure 2, the relationship between voltage and current can be stated as follows: **IN AN ELECTRIC CIRCUIT, WHEN THE RESISTANCE IS HELD CONSTANT, THE CURRENT IS DIRECTLY PROPORTIONAL TO THE VOLTAGE.**



The French physicist, André Ampère, contributed greatly to the progress of electronics. Among the results of his experiments were the electromagnet and other devices which use electricity to produce magnetism. The unit of current, the ampere, is named in his honor.

Courtesy Ohmite Manufacturing Co.

Resistance and Current

In the previous example, the resistance was held constant and the voltage was varied to produce a change in current. However, the current also varies with a change in resistance. Using the circuit shown in Figure 2 once again, this time assume that the voltage is held constant. We can now study the relationship between resistance and current.

If the battery voltage shown in Figure 2 is 1 volt, and the resistance is 1 ohm, the current is 1 ampere. However, if the resistance is increased in value to 2 ohms, there is then twice as much opposition to electron flow. Doubling the opposition reduces the current to one-half its original value. Therefore, with 1 volt applied to the circuit, and the resistance increased to 2 ohms, the current is only $1/2$ an ampere.

Conversely, a decrease in resistance means that the opposition to electron flow has decreased, and the current increases accordingly. Thus, if the voltage is still 1 volt, and the resistance is decreased in value to half an ohm, the current will increase to 2 amperes. This type of relationship is referred to as an **INVERSE PROPORTION**, and we can use the results of this example to form the general statement: **IN AN ELECTRIC CIRCUIT, WHEN THE VOLTAGE IS HELD CONSTANT, THE CURRENT IS INVERSELY PROPORTIONAL TO THE RESISTANCE.**

Voltage, Current and Resistance

The relationship between voltage and current can be combined with the relationship between current and resistance to form the complete Ohm's Law. This law may be stated as follows:

**IN ANY ELECTRIC CIRCUIT, THE CURRENT IS
DIRECTLY PROPORTIONAL TO THE VOLTAGE,
AND INVERSELY PROPORTIONAL TO
THE RESISTANCE.**

In modern electronics, we want to know exactly how much the current changes if the voltage or resistance varies by a certain amount. Ohm's Law

VOLTAGE, CURRENT AND RESISTANCE

is a valuable tool in this respect, since it allows us to determine the current when the voltage and resistance are known. In practice, this relationship is expressed as a guide used for calculation, or what we call an "equation," and it is stated as follows:

$$\text{CURRENT} = \text{VOLTAGE} \div \text{RESISTANCE.}$$

To explain this relationship, assume the voltage shown in Figure 2 is 10 volts and the resistance is 2 ohms. By inserting these values into the Ohm's Law equation, the current may be determined as follows:

$$\begin{aligned}\text{Current} &= \text{Voltage} \div \text{Resistance} \\ &= 10 \div 2 \\ &= 5 \text{ amperes.}\end{aligned}$$

For another example, assume the voltage shown in Figure 2 is 100 volts, and the resistance is 25 ohms. These values can be used in the Ohm's Law equation as follows:

$$\begin{aligned}\text{Current} &= \text{Voltage} \div \text{Resistance} \\ &= 100 \div 25 \\ &= 4 \text{ amperes.}\end{aligned}$$

Thus, the current can be found for any combination of voltage and resistance. For convenience, the standard letter symbols usually are inserted in place of the terms "voltage," "current" and "resistance." Then, the expression becomes:

$$\mathbf{I = E \div R.}$$

In working with equations, it is customary to indicate division by placing the values one above the other. A "bar" is then used between the numbers to show that the value above the bar is divided by the value below the bar. The usual way of expressing Ohm's Law is as follows:

$$I = \frac{E}{R} \quad (1)$$

Sometimes the fraction bar is slanted as shown below:

$$I = E/R.$$

In applying Ohm's Law, the voltage value (expressed in volts) is inserted in place of the E; the resistance value (expressed in ohms) is inserted in place of the R. The current value (expressed in amperes) then appears in place of the I.



Allesandro Volta, an Italian physicist, developed the first battery. As a result, great advances were made possible in the field of electrical experimentation. The term "voltage" and its unit (volt) were named in his honor. Courtesy Ohmite Manufacturing Co.

There may be times when the current is known, and the voltage or resistance must be found. If so, the Ohm's Law equation can be rearranged to find the desired quantity. When any two of the three quantities are known, the re-

VOLTAGE, CURRENT AND RESISTANCE

maining one can be determined. The form of Ohm's Law that allows us to calculate voltage is expressed as follows:

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

or using the standard symbols for convenience:

$$E = IR. \quad (2)$$

Notice that the multiplication sign ($\times$) is omitted between I and R in the above equation. When symbols are written next to each other, without a sign of any kind between them, the values represented by these symbols are to be multiplied by each other.

To expand upon this form of the Ohm's Law equation, let's assume that the current shown in Figure 2 is 2 amperes, and the resistance is 25 ohms. The voltage is then found by multiplying the current by the resistance:

$$\begin{aligned} E &= IR \\ E &= 2 \times 25 \\ &= 50 \text{ volts.} \end{aligned}$$

The form used to determine resistance when the voltage and current are known is expressed as:

$$\text{Resistance} = \text{Voltage} \div \text{Current}$$

or, again using standard symbols for convenience:

$$R = \frac{E}{I} \quad (3)$$

As an example, assume the voltage shown in Figure 2 is 20 volts and the current is 2 amperes. The resistance is then found by dividing the voltage by the current:

$$\begin{aligned} R &= \frac{E}{I} \\ R &= \frac{20}{2} \\ &= 10 \text{ ohms.} \end{aligned}$$

Figure 3 is a diagram which is used as an aid in finding E, I or R when the other two terms are given. The use of this diagram is shown in Figure 4. By placing your finger on the symbol for the value you want to find, two of the symbols are left exposed. If both of the exposed symbols are below the horizontal line, as shown in Figure 4A, they must be multiplied. If one exposed symbol is above the horizontal line, as shown in Figures 4B and 4C, the top value is divided by the exposed value below the horizontal line.

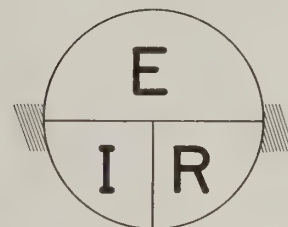


Figure
3

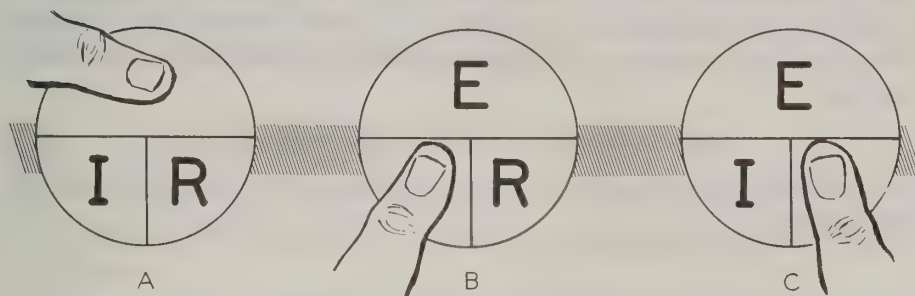


Figure 4

As an example of how the diagram is used, assume that the current and resistance of a circuit are known, and the voltage is to be determined. With the finger placed over the E, as shown in Figure 4A, the diagram indicates that the current is to be multiplied by the resistance.

If the voltage and resistance are known, and the current is to be determined, the finger is placed over the I. As shown in Figure 4B, the exposed symbols indicate that the voltage is divided by the resistance to determine the current.

In Figure 4C, the finger is placed over the R, and the diagram indicates that a known value of voltage is divided by a known value of current if the resistance is to be determined.

There are many uses for Ohm's Law in all branches of electronics. For example, assume the current in some device must be limited to a certain value to make sure that the device will not overheat and burn up. If the amount of voltage applied to the device is known, this value can be divided by the "safe" amount of current to determine what value of resistance the circuit must have.

MILLIAMPERES AND MICROAMPERES

Many electronic circuits require less than 1 ampere (amp) of current for normal operation. To keep from specifying current values in fractions of an ampere, it is common practice to use units that are smaller than an ampere. These units were introduced in an earlier lesson and now will be used in typical problems.

One of these units is the MILLIAMPERE (mA), which is one-thousandth of an ampere. Remember that a milliampere is **ONE THOUSAND TIMES SMALLER** than an ampere, and therefore it takes 1000 milliamperes to make 1 ampere.

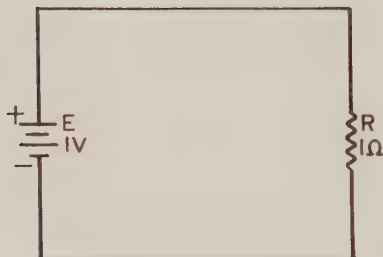


Figure
5A

To gain a better understanding of how the milliampere is used, let's look at some circuits.

In the circuit shown in Figure 5A, the source voltage is 1 volt and the load resistance is 1 ohm. Using Ohm's Law to determine the current we get:

$$I = \frac{E}{R}$$

$$I = \frac{1}{1}$$

$$= 1 \text{ ampere.}$$

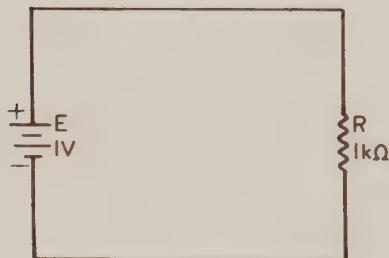


Figure
5B

In the circuit shown in Figure 5B, the source voltage is still 1 volt; however, the load resistance now is 1 kΩ (1000 ohms). Again using Ohm's Law to determine the current, we get:

$$I = \frac{E}{R}$$

$$I = \frac{1}{1000} \text{ ampere}$$

dividing 1000 into 1 gives

$$1000 \overline{) \begin{array}{r} .001 \\ 1.000 \\ \underline{1000} \end{array}} \text{ ampere}$$

$$= .001 \text{ ampere.}$$

The following Practice Exercise questions cover the subjects which you have just studied. They are:

STANDARD UNITS

OHM'S LAW

VOLTAGE AND CURRENT

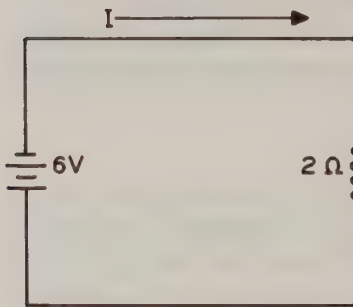
RESISTANCE AND CURRENT

VOLTAGE, CURRENT AND RESISTANCE

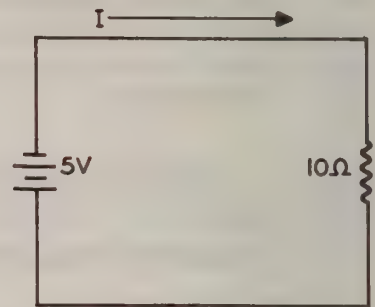
1. The rate of electron flow is measured in (a) amperes, (b) volts, (c) ohms.
2. A _____ is the electric pressure required to produce an ampere of current in a circuit having one _____ of resistance.
3. Electric pressure (—) is measured in _____ (V); the rate of electron flow (—) is measured in amperes (—); the _____ (R) is measured in ohms (—).
4. In electronics, Ω is the symbol for the unit _____.
5. Voltage and current in a circuit (a) have no fixed relationship, (b) are directly proportional, (c) are inversely proportional.
6. According to Ohm's Law, cutting the resistance in half has the same effect on current as (a) cutting the voltage in half, (b) increasing the voltage four times, (c) doubling the voltage.
7. If the applied voltage in a circuit is held constant, what happens to the current when the resistance is reduced to $1/5$ of its original value?
8. If the resistance in a circuit is doubled and voltage increased to four times its original value, the current (a) doubles, (b) remains the same, (c) reduces to half.

9. Current equals _____ divided by _____.

10. What are the currents in the circuits below?



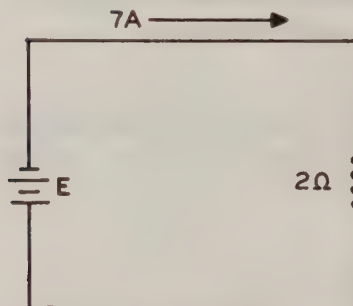
A



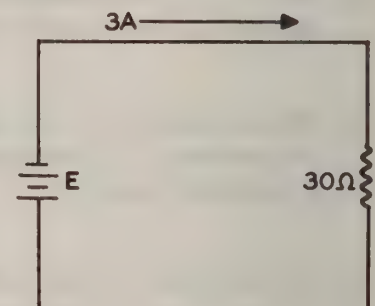
B

11. Voltage equals _____ times _____.

12. What are the battery voltages in the circuits below?



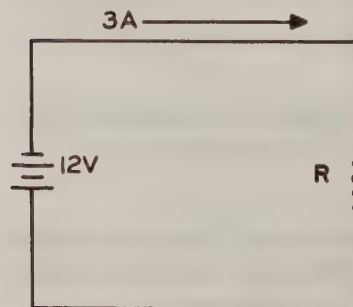
A



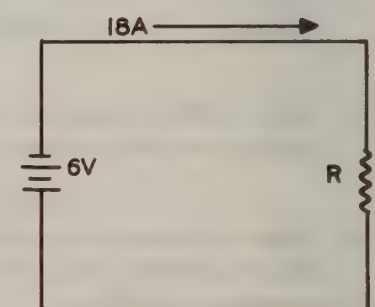
B

13. Resistance equals _____ divided by _____.

14. What are the resistances in the circuits below?



A



B

To convert amperes to milliamperes (mA), it is necessary to move the decimal point three places to the right (this is the same as multiplying the number by 1000), as follows:

$$\begin{aligned} I &= .001 \text{ ampere} \\ &= \underline{.001} \text{ mA} \\ &= 1 \text{ mA.} \end{aligned}$$

The curved arrow in the middle step just above shows the decimal point being moved three places to the right. Also, milliampere (mA) is substituted for ampere.

In the circuit shown in Figure 5C, the source voltage is 24 volts and the load resistance is 2 k Ω (2000 ohms). Using Ohm's Law to determine the current, and converting amperes to milliamperes, we get:

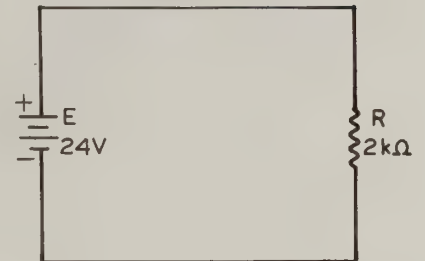


Figure 5C

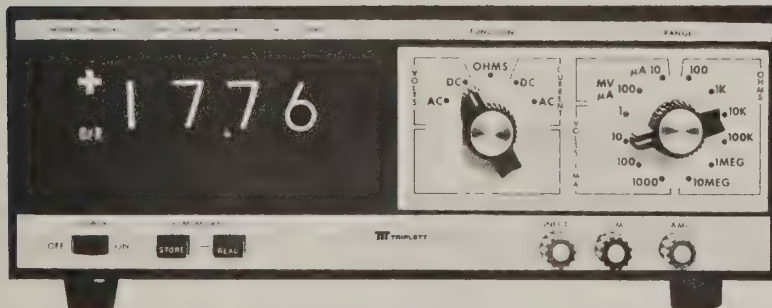
$$I = \frac{E}{R}$$

$$I = \frac{24}{2000} \text{ ampere} \rightarrow 2000 \sqrt{\frac{.012}{24.000}} \text{ ampere}$$

$$= .012 \text{ ampere}$$

$$= .012 \text{ mA. Moving the decimal point three places to the right results in the current being expressed in milliamperes:}$$

$$= 12 \text{ mA.}$$



Digital meters can be used to provide accurate readings of voltage, current and resistance.

Courtesy Triplett Corp.

VOLTAGE, CURRENT AND RESISTANCE

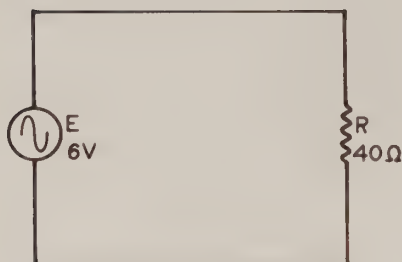


Figure
5D

To determine the amount of current in the circuit shown in Figure 5D, use Ohm's Law and then convert the answer from amperes to milliamperes as follows:

$$I = \frac{E}{R}$$

$$I = \frac{6}{40} \text{ ampere} \rightarrow 40 \overline{) .15} \text{ ampere}$$

$$= .15 \text{ ampere}$$

$$= .150 \text{ mA} \quad \text{It is necessary to add a zero after the .15 in order to move the decimal point three places to the right:}$$

$$= 150 \text{ mA.}$$

When working with electric circuits, it often happens that you know the resistance and current and wish to determine the voltage. To find the voltage, use the $E = IR$ form of Ohm's Law. Make sure all quantities are in basic units. That is, E is in volts, I is in amperes and R is in ohms. The current in many circuits is less than 1 ampere and it is specified in milliamperes for convenience. Let's assume that circuit current is 18 mA (.018A) and circuit resistance is 500 ohms. To determine the circuit voltage, use Ohm's Law, as follows:

$$E = IR$$

$$E = 18 \text{ mA} \times 500 \text{ ohms.}$$

Since Ohm's Law requires the current to be in amperes, you must convert milliamperes to amperes. To do this, move the decimal point three places to the left:

$$E = 18 \text{ mA} \times 500\Omega$$

$$E = .018 \text{ A} \times 500\Omega. \quad \text{It is necessary to add a zero to the left of the number 18 in order to move the decimal point three places to the left:}$$

$$= .018 \text{ A} \times 500\Omega$$

$$= 9 \text{ volts.}$$

Regardless of the type of circuit or equipment involved, milliamperes are converted to amperes by moving the decimal point three places to the left. Another unit of current commonly used in electronics is the MICROAMPERE (μA), which is one-millionth of an ampere. A microampere is such a small amount of current that it takes one million of them to make an ampere. To convert from amperes to microamperes, move the decimal point six places to the right. For example, let us determine the current in the circuit shown in Figure 6. Using Ohm's Law, we get:

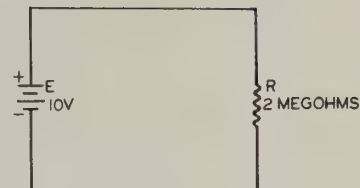


Figure
6

$$I = \frac{E}{R}$$

$$I = \frac{10}{2,000,000} \text{ ampere} \rightarrow 2,000,000 \overline{) 10.000000} \text{ ampere}$$

$$= .000005 \text{ ampere.}$$

Converting amperes to microamperes, move the decimal point 6 places to the right:

$$I = .000005 \text{ ampere}$$

$$= .000005 \text{ microamperes}$$

$$= 5 \text{ microamperes.}$$

Sometimes it is necessary to convert microamperes to amperes. This is accomplished by moving the decimal point six places to the left, as follows:

$$8 \mu\text{A} = \underline{\quad? \quad} \text{ ampere}$$

$$8 \mu\text{A} = .000008 \text{ ampere.}$$

It is necessary to add five zeros to the left of the number eight so that the decimal point can be moved six places to the left:

$$8 \mu\text{A} = .000008 \text{ ampere.}$$

VOLTAGE, CURRENT AND RESISTANCE

For your convenience, the chart of Figure 7 summarizes the conversion of amperes to mA, A to μ A, mA to A, and μ A to A.

TO CONVERT		MOVE DECIMAL POINT	EXAMPLE
TO	FROM		
A	mA	3 PLACES TO RIGHT	$43\text{A} = \underline{430} = 430\text{ mA}$
A	μ A	6 PLACES TO RIGHT	$.000055\text{A} = \underline{.000055} = 55\text{ }\mu\text{A}$
mA	A	3 PLACES TO LEFT	$68\text{mA} = \underline{.068} = .068\text{ A}$
μ A	A	6 PLACES TO LEFT	$235\text{ }\mu\text{A} = \underline{.000235} = .000235\text{ A}$

Figure 7

SUMMARY

In an electric circuit, there is a definite relationship between voltage (E), current (I) and resistance (R). This relationship is known as Ohm's Law.

According to Ohm's Law, the current in a circuit is directly proportional to the voltage applied to the circuit, and inversely proportional to the circuit resistance. Thus, the current increases when the voltage is increased, and the current decreases when the resistance is increased.

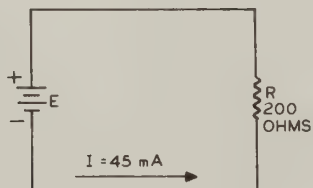
Whenever two of the three quantities (E, I and R) are known, one of the three Ohm's Law equations is used to calculate the unknown quantity. These equations are: $I = E/R$, $E = IR$ and $R = E/I$.

The basic unit for measurement of current is the ampere (A). When the circuit current is stated milliamperes (mA) or microamperes (μ A), the value is converted to amperes (the basic unit) in order to use it in an Ohm's Law equation.

The following Practice Exercise questions cover the subject which you have just studied. It is:

MILLIAMPERES AND MICROAMPERES

15. How many milliamperes (mA) are in one ampere?
16. Convert the following to milliamperes (mA): .25 ampere, .037 ampere, 1.6 amperes, .005 ampere.
17. In a circuit where the source voltage is 600 volts and the total resistance is $15\text{ k}\Omega$ (15,000 ohms), what is the circuit current in mA?
18. Convert the following to amperes (A): 150 mA, 45 mA, 370 mA, 6500 mA, 8 mA, 80 mA, 800 mA, 8000 mA.
19. In the circuit below, how many volts is the battery supplying?



20. Convert the following to microamperes (μA): .072 ampere, .0025 ampere, .000043 ampere, .0007 ampere.
21. In the circuit shown in Figure 6, if the 10-volt battery is replaced with a 160-volt battery, what is the circuit current in μA ?
22. Convert the following to amperes: 2 μA , 25 μA , 147 μA .

IMPORTANT DEFINITIONS

AMPERE—The basic unit of current in an electric circuit.

DIRECT PROPORTION—A relationship by which a change in one quantity produces exactly the same change in another quantity. If doubling one quantity causes the other quantity to be doubled, the two quantities are said to be directly proportional.

INVERSE PROPORTION—A relationship by which a change in one quantity produces exactly the opposite change in another quantity. If doubling one quantity causes the other quantity to decrease to one-half its original value, the two quantities are said to be inversely proportional.

OHM—The basic unit of resistance in an electric circuit.

OHM'S LAW—A law which describes the relationship between voltage, current and resistance in an electric circuit. In an electric circuit, the current is directly proportional to the voltage, and inversely proportional to the resistance.

VOLT—The basic unit of voltage in an electric circuit.

ESSENTIAL SYMBOLS AND EQUATIONS

E Voltage (volts)

I Current (amperes)

R Resistance (ohms)

$$I = \frac{E}{R} \quad (1)$$

$$E = IR \quad (2)$$

$$R = \frac{E}{I} \quad (3)$$

PRACTICE EXERCISE SOLUTIONS

1. (a) amperes.
2. volt; ohm
3. E; volts; I; A; resistance; Ω
4. ohm.
5. (b) are directly proportional.—Assuming that the resistance doesn't change, the number of electrons flowing in a circuit varies directly with the electric pressure.
6. (c) doubling the voltage.—A change in resistance and a change in voltage have equal but opposite effects on current. That is, they are inversely proportional.
7. The current will increase to 5 times its original value, since current is inversely proportional to the resistance.
8. (a) doubles.—The change of resistance alone would reduce the current to one-half its original value and the change in voltage alone would cause a fourfold increase in current. The combined result ($1/2 \times 4$) is a doubling of current.
9. voltage; resistance.
10. A: $I = \frac{E}{R} = \frac{6}{2} = 3\text{A.}$ B: $I = \frac{E}{R} = \frac{5}{10} = \frac{1}{2}\text{A.}$
11. current; resistance
12. A: $E = IR = 7 \times 2 = 14\text{V.}$ B: $E = IR = 3 \times 30 = 90\text{V.}$
13. voltage; current

PRACTICE EXERCISE SOLUTIONS (Continued)

14. A: $R = \frac{E}{I} = \frac{12}{3} = 4\Omega$. B: $R = \frac{E}{I} = \frac{6}{18} = \frac{1}{3}\Omega$.

15. There are 1000 milliamperes in 1 ampere.

16. 250 mA; 37 mA; 1600 mA; 5 mA.

17. 40 mA.— $I = \frac{E}{R} = \frac{600}{15,000} = .04$ ampere. Converting amperes to milliamperes by moving the decimal point three places to the right gives $.04A = 40$ mA.

18. .15A; .045A; .37A; 6.5A; .008A; .08A; .8A; 8A.

19. 9 volts.— $E = IR = .045 \times 200 = 9$ volts.

20. 72,000 μA ; 2500 μA ; 43 μA ; 700 μA .

21. 80 μA .— $I = \frac{E}{R} = \frac{160}{2,000,000} = .00008$ ampere = 80 μA .

22. .000002 ampere; .000025 ampere; .000147 ampere.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE
1007A

Example:

A	
B	
C	
D	

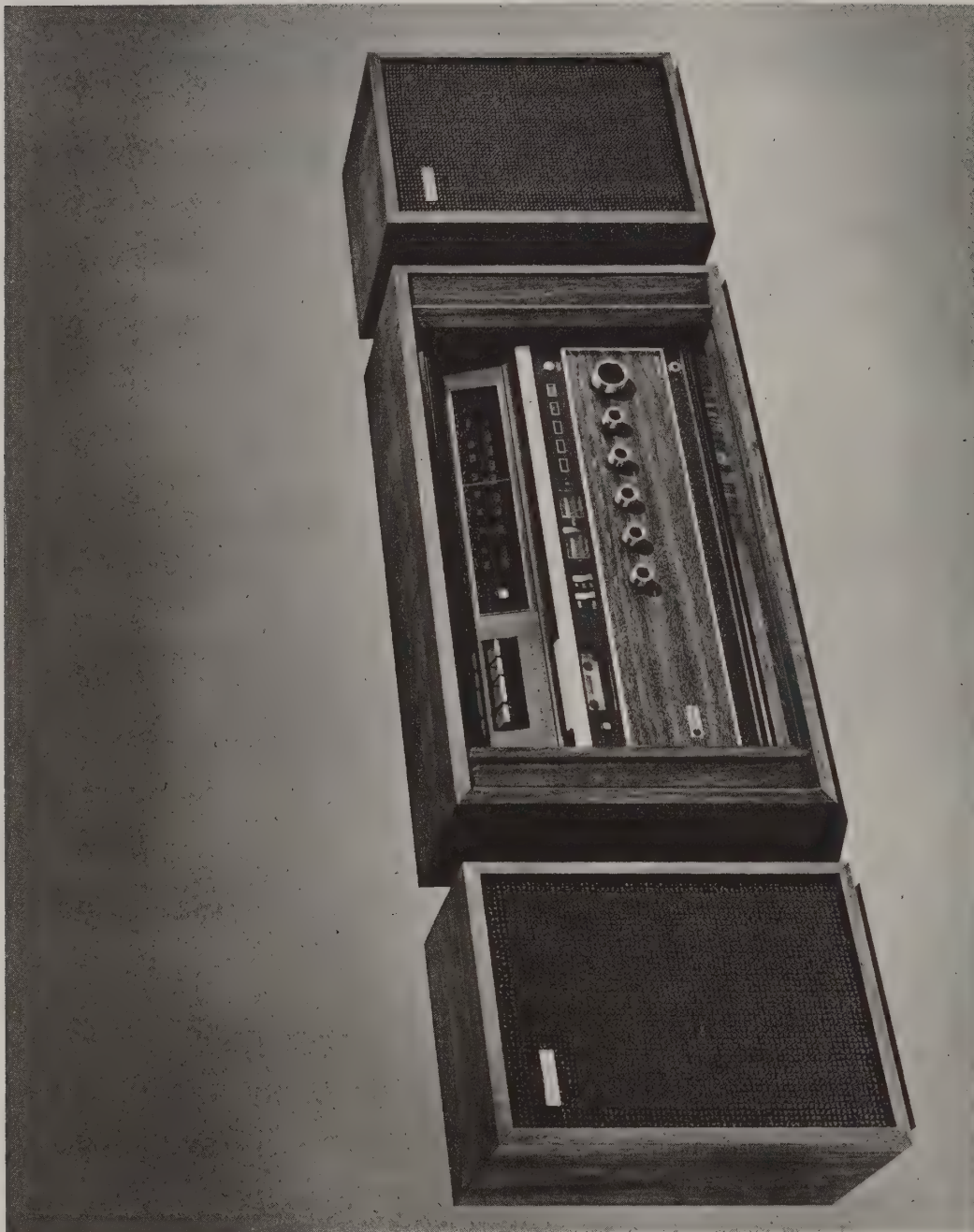
A thermometer measures

A. temperature. B. speed. C. time. D. distance.

1. A ☐ Voltage and current are
 B ☐ (A) measured in the same units. (B) inversely proportional. (C) directly proportional. (D) always larger than the resistance.
 C ☐
 D ☐
2. A ☐ Resistance and current are
 B ☐ (A) measured in the same units. (B) directly proportional. (C) inversely proportional. (D) always smaller than the voltage.
 C ☐
 D ☐
3. A ☐ If the voltage applied to a circuit is doubled and the resistance remains the same,
 B ☐ the current
 C ☐ (A) remains the same. (B) is halved. (C) is doubled. (D) decreases in proportion.
 D ☐
4. A ☐ In an electric circuit, when the voltage and resistance are known, which form of
 B ☐ the Ohm's Law equation is used to directly find the current?
 C ☐
 D ☐ (A) $E = IR$ (B) $R = \frac{E}{I}$ (C) $I = \frac{E}{R}$ (D) $R = IR$
5. A ☐ In an electric circuit, if the current is 20 amperes and the source voltage is 400
 B ☐ volts, the circuit resistance is
 C ☐ (A) 8000 ohms. (B) 20 ohms. (C) 420 ohms. (D) 380 ohms.
 D ☐
6. A ☐ In an electric circuit, if the current is 25 milliamperes (.025 ampere) and the re-
 B ☐ sistance is 5000 ohms, the source voltage is
 C ☐ (A) 125 volts. (B) 200 volts. (C) 1250 volts. (D) 5 volts.
 D ☐
7. A ☐ In an electric circuit, if the voltage is 100 volts and the resistance is 25 k Ω (25,000
 B ☐ ohms), the current is
 C ☐ (A) 25 mA (.025A). (B) 4 mA (.004A). (C) 40A. (D) 25A.
 D ☐
8. A ☐ A milliampere is
 B ☐ (A) one thousand times smaller than an ampere. (B) one thousand times larger
 C ☐ than an ampere. (C) one million times smaller than an ampere. (D) one million
 D ☐ times larger than a microampere.
9. A ☐ When using any form of Ohm's Law, how many values must be KNOWN?
 B ☐ (A) Three. (B) None. (C) One. (D) Two.
 C ☐
 D ☐
10. A ☐ Ohm's Law is used
 B ☐ (A) only when the source voltage is dc. (B) only when the source voltage is ac.
 C ☐ (C) when the source voltage is dc or ac. (D) only when the source voltage is
 D ☐ greater than 10 volts.

SERIES AND PARALLEL CIRCUITS

1010



The circuits in home entertainment music systems as well as in all other types of electronic equipment are combinations of series and parallel circuits.

Courtesy Bell & Howell

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Parallel Circuits	Page 22
Appendix—Calculating the Total Resistance of Parallel Circuits	Page 35

I don't think much of a man who is not wiser today than he was yesterday.

—Abraham Lincoln

SERIES AND PARALLEL CIRCUITS

In order to do useful electrical work, a complete circuit for the electron flow is required. The complete circuit may be as simple as a flashlight or it may be as elaborate as a modern electronic computer. However, certain basic properties are common to all circuits, no matter how simple or elaborate they may be. In this lesson we will consider the basic rules that govern all electric circuits. These rules form the basis for the entire field of electronics. In addition, this lesson will present methods of measuring circuit voltage and current, as well as identifying circuit components.

VOLTMETERS

To help us measure electric and electronic quantities, several instruments are used. One of these instruments (the **VOLTMETER**) measures the electric pressure (emf), or potential difference, between any two points in a circuit. The use of the voltmeter is quite simple.

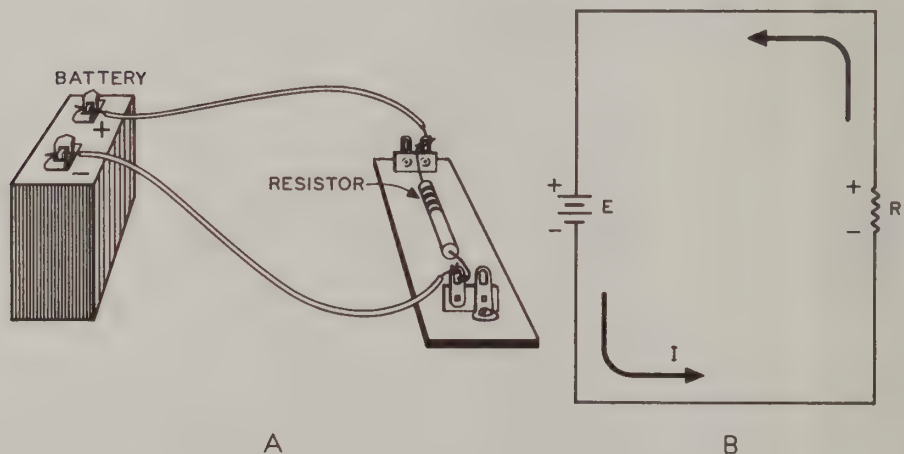


Figure 1

Suppose, for example, that you wish to investigate a circuit consisting of a battery as the voltage source and a resistor as the load. Figure 1A shows one way in which the two components can be connected. Rather than connecting the resistor directly across the battery terminals, the two resistor leads are connected to separate tie points. Lengths of hookup wire are then connected from the battery terminals to the tie points. In practically all

electronic equipment, the resistors and other components are physically attached to some sort of tie points. Wire is then connected between the various tie points to complete the circuit. Where permanent connections are desired, the tie points are soldered.

For convenience, the circuit of Figure 1A is represented by the schematic diagram of Figure 1B. The direction of current is indicated by the arrows, and the polarity of the voltage across the resistor by the plus and minus signs.

A resistor has no polarity of its own. However, when we connect a resistor into a circuit, the current through it produces a voltage across the resistor. The direction of the current through the resistor determines the polarity of the voltage across the resistor. The end of the resistor which the electron current enters is negative and the end which the current leaves is positive.

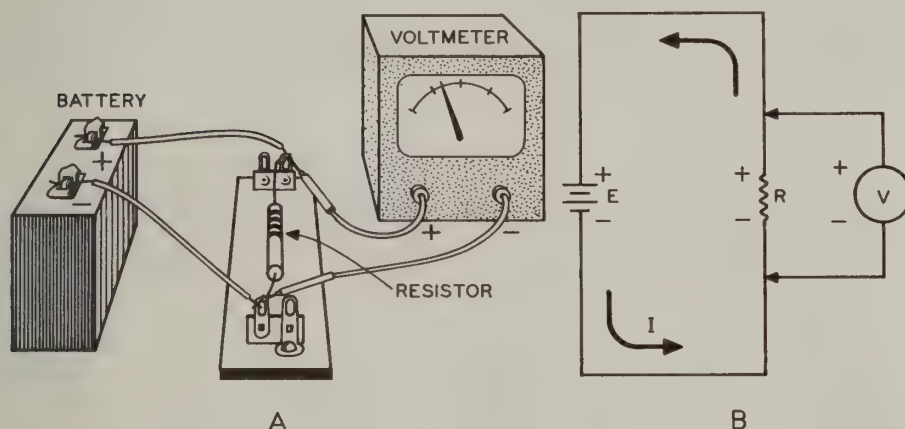


Figure 2

To measure the voltage across the resistor, a voltmeter is connected across the resistor as shown in Figure 2A. Notice that the positive terminal of the voltmeter is connected to the positive end of the resistor, and the negative terminal of the voltmeter is connected to the negative end of the resistor.

The circuit shown in Figure 2A is represented by the schematic diagram shown in Figure 2B. Current flows from the negative battery terminal to the lower end of the resistor, up through the resistor and over to the positive battery terminal. The current through the resistor causes a voltage across it with the indicated polarity. The voltmeter is connected directly across the resistor. The polarity of the meter leads is as indicated in the figure.

SERIES AND PARALLEL CIRCUITS

Notice that the circuit of Figure 2B is identical to the circuit of Figure 1B. The addition of the voltmeter in Figure 2B does not affect the basic operation of the circuit. The voltmeter can be removed without changing the basic circuit action.

Also notice in Figures 2A and 2B that only two lengths of wire separate the voltmeter leads and the battery terminals. Electrically, then, the voltmeter is connected across the battery as well as across the resistor, and indicates that the same voltage is across both components. This is the case when a single voltage source is connected into a circuit with a single load—the voltage across the load is then the source voltage.

AMMETERS

Another very useful instrument is the **AMMETER**, which measures the electric current in a circuit. The ammeter is also very simple to use, as only two connections are required between it and the circuit. However, the method of connecting the ammeter is different than the method of connecting the voltmeter.

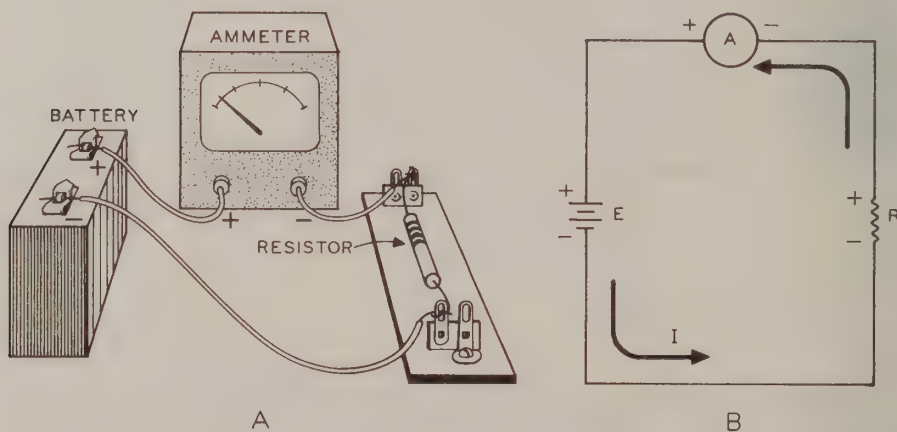


Figure 3

To measure the current in the circuit shown in Figure 1, an ammeter is connected so that the circuit appears as in Figures 3A and 3B. Here, the path for current is from the negative battery terminal through the resistor, to the negative ammeter terminal, through the ammeter and back to the positive battery terminal. Look closely at Figure 3A. Notice particularly the manner in which the ammeter is connected. The ammeter is a part of the complete

circuit and the *current to be measured must flow through it*. If the ammeter is removed from the circuit and nothing else is done to the circuit, the circuit is incomplete and there is no path for current. To measure the current *through* a circuit, the ammeter is connected so that the circuit current also passes *through* it.

When any device or component, such as an ammeter, is connected so that the circuit current must pass through it, it is said to be connected in **SERIES** with the other parts of the circuit. A voltmeter is connected across or in **PARALLEL** with the component whose voltage we wish to measure.

Figure 4A shows how an ammeter and voltmeter can be connected into a circuit to measure both voltage and current at the same time. Note that the voltmeter is connected in parallel with the circuit while the ammeter is connected in series with the circuit. Figure 4B shows the schematic representation of the circuit of Figure 4A.

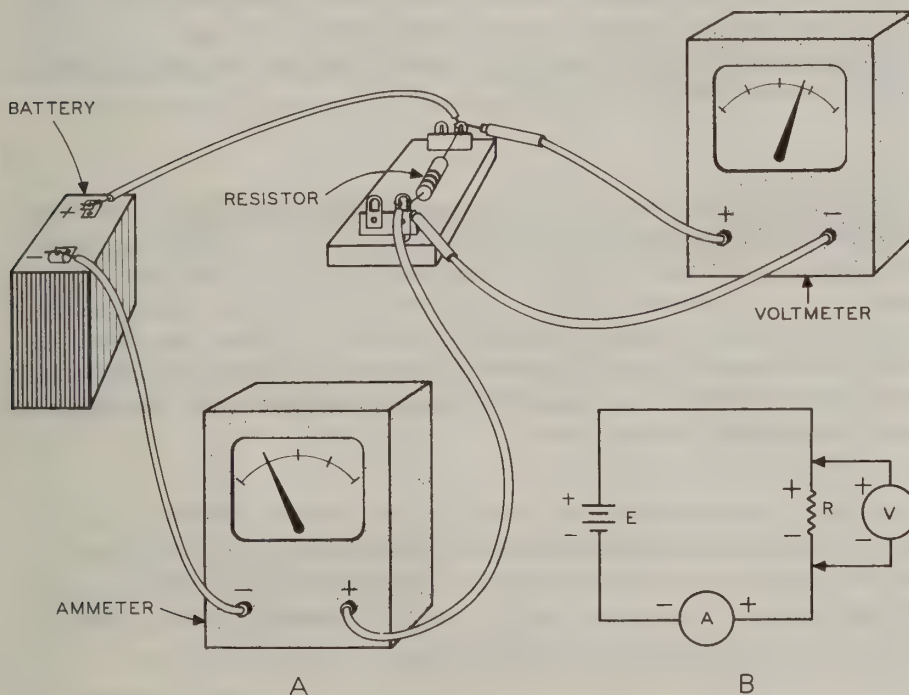


Figure 4

SUBSCRIPTS

The ability to read schematic diagrams is important in all branches of electronics. Very simple circuits, of course, have very simple schematic dia-

SERIES AND PARALLEL CIRCUITS

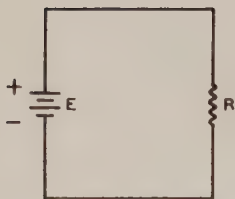
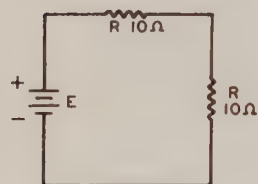
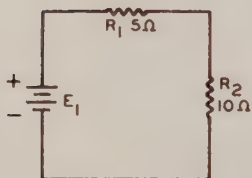


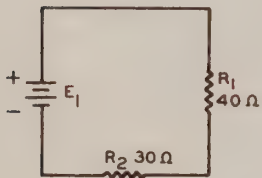
Figure
5



A



B



C

Figure
6

grams. There is not much of a problem in tracing out current paths or identifying electronic parts of very simple circuits. For example, Figure 5 is the schematic diagram of a circuit containing a battery as the voltage source and a resistor as the load. No identification problem exists here. Any reference to a voltage source or a resistance must necessarily mean the only battery or the only resistor in the circuit.

However, in most electronic devices more than one resistor is supplied with voltage and current at the same time. A common circuit is shown in Figure 6A, where two resistors are the load for the source. Immediately, a problem arises of identifying one resistor from the other. We could identify one resistor by saying "the resistor which has one end connected to the positive terminal of the battery," and the other resistor could be identified by saying "the resistor which has one end connected to the negative terminal of the battery." Even this lengthy description might be acceptable if each circuit contained only two or three resistors. However, a modern transistor radio receiver may contain over 25 resistors while a color television receiver may have more than 300. Because of the large number of components in electronic equipment, a better system of identification must be used to distinguish one component from another.

Figure 6B shows the system of component identification used in the electronics industry. Instead of labeling the resistors with a plain letter *R* and the battery with a plain letter *E*, a number is placed to the right of, and slightly below, each letter symbol. Thus, the two resistors in Figure 6B are labeled R_1 and R_2 , while the battery is labeled E_1 . Since the identifying numbers are placed slightly below the letter designations, the numbers are called **SUBSCRIPTS**. The system of labeling components with subscripts is called **SUBSCRIPT NOTATION**.

Figure 6C is another example of the use of subscripts. Notice that in Figures 6B and 6C the resistance values of the resistors have no bearing on the subscript numbers. In Figure 6B, R_1 has less resistance than R_2 , while in Figure 6C, R_1 has more resistance than R_2 .

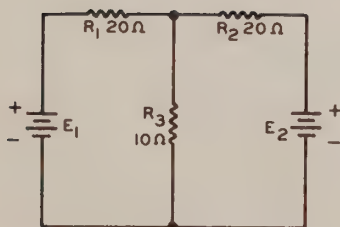


Figure
7

Subscripts are used to identify all types of components used in electric circuits. In the schematic diagram shown in Figure 7, we show a circuit with three resistors and two batteries. By using subscript notation, we can distinguish between the resistors, and also between the batteries. Now, to describe the effects of E_2 on the circuit, we simply say, "Electric current is from the negative terminal of E_2 , through R_3 , through R_2 , and back to the positive terminal of E_2 ." Just try to think of a simple way to say this without using subscripts to identify the components.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

VOLTMETERS

AMMETERS

SUBSCRIPTS

1. To measure the voltage across a resistor, an ammeter is connected across the resistor. True or False?
2. To measure the current flowing through a resistor, a voltmeter is connected across the resistor. True or False?
3. The polarity of the voltage across a resistor is determined by the direction of the _____ through the resistor.
4. Voltmeter polarity does not have to be observed when measuring voltage across a resistor. True or False?
5. In a complete circuit, such as Figure 2B, what instrument should you use to measure the electromotive force (emf) of the source?
6. In the circuit shown in Figure 3B, the meter being used to measure current is an _____.
7. When current must pass through a measuring device, it must be connected in _____ with the other parts of the circuit.
8. A device used to measure voltage must be connected in _____ with the part whose voltage is to be measured.

9. Subscripts are never used to identify components in an electronic circuit. True or False?
10. When subscripts are used to identify resistors, the resistor with the least resistance is always labeled R_1 . True or False?
11. Subscripts are used to help identify (a) only the resistances in a circuit, (b) only the batteries in a circuit, (c) all components in a circuit.
12. The system of labeling components with subscripts is called _____.

REFERENCE POINTS

Often, the phrases **POSITIVE VOLTAGE** and **NEGATIVE VOLTAGE** are used rather loosely. A battery, for example, produces neither a positive voltage nor a negative voltage. It does produce a voltage between its two terminals so that the plus terminal is positive with reference to the minus terminal, and the minus terminal is negative with reference to the plus terminal. The phrase "with respect to" is often used in place of "with reference to."

Notice that the voltage is specified as being positive, or negative, with reference to another point. This concept of voltage being between two points also applies to complete circuits. Referring to Figure 8, we see the 6 ohm resistor, R_1 , connected across the 6 volt battery, E_1 . The 12 ohm resistor, R_2 , is connected across the 12 volt battery, E_2 . Since E_1 and R_1 are connected as a complete circuit, E_1 forces one ampere through R_1 , making the resultant voltage across R_1 6 volts and point A positive with respect to point B.

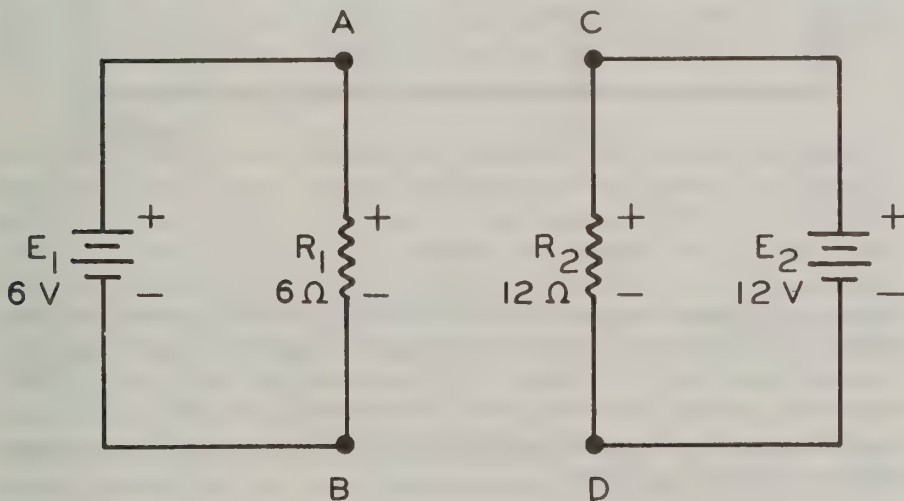


Figure 8

A similar situation exists in the circuit containing E_2 and R_2 . The resultant voltage across R_2 is 12 volts positive at point C with respect to point D.

Since the circuit containing E_1 and R_1 is completely independent of the circuit containing E_2 and R_2 , a point in one circuit cannot be compared with a

SERIES AND PARALLEL CIRCUITS

point in the other circuit. That is, we cannot say that the voltage at point A is positive with respect to point D.

In order to compare point A with either point C or D, it is necessary for the two circuits to have something in common. This condition is shown in Figure 9, where points B and D are connected together. Now, the voltage at point A is 6 volts positive with respect to both points B and D. Also, the voltage at point C is 12 volts positive with respect to both points B and D.

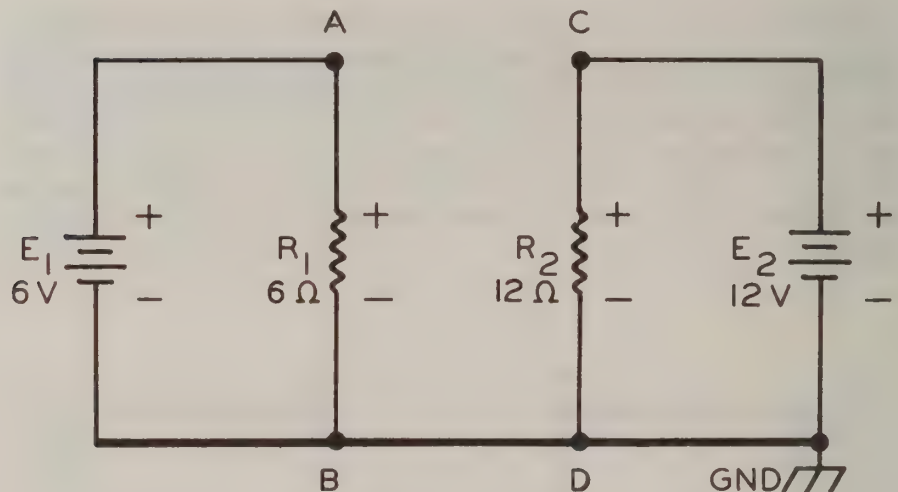


Figure 9

In most equipment there are several circuits which have a common connection. This common connection is indicated in some schematic diagrams by a wide, dark line, as in Figure 9. It is common practice to use the metal chassis as a common connecting line. The schematic diagram usually indicates this condition by adding a **GROUND** (GND) symbol to the common connecting line, as in Figure 9.

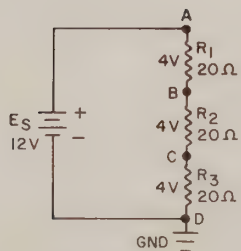


Figure 10

The word "ground" does not necessarily mean "earth ground." Any point used as a common reference point in a circuit may be called ground.

The schematic diagram of Figure 10 shows a method of connecting resistors which is found in almost all electric or electronic equipment. This circuit is arranged so that the source voltage is divided between three resistors. Each resistor has 20 ohms of resistance; therefore, the source voltage divides equally between them. Since the source voltage is 12 volts, there are 4 volts across each resistor.

Notice that the ground symbol in Figure 10 is different than the one used in Figure 9. We show this symbol because both it and the symbol of Figure 9 are used to indicate a common reference point.

In Figure 10, point A is connected directly to the positive battery terminal, and point D is connected directly to the negative battery terminal; therefore, the voltage between points A and D is 12 volts. Point A is also 12 volts positive with respect to point D.

Assume that we use point D (or ground) as the common reference point. Then, with respect to the reference point, point A is 12 volts positive, point B is 8 volts positive and point C is 4 volts positive. Keep in mind that a voltage exists **BETWEEN TWO POINTS**. When someone says that a particular point in a circuit is positive (or negative), he usually means that the point is positive (or negative) with respect to the reference point in the circuit.

The schematic diagram shown in Figure 11 is almost identical to the one shown in Figure 10. The only difference is that the ground point in Figure 11 is at point C, whereas the ground point in Figure 10 is at point D. Nothing else was changed. There is still 4 volts across each of the three resistors.

Let's take another look at Figure 10. In Figure 10, we said that point C was 4 volts positive when using ground as the reference point. In Figure 11, point C is ground and there is zero voltage between point C and ground. Since the ground point has been changed, the voltages at all other points in the circuit change with respect to ground. Point A is now 8 volts positive, point B is 4 volts positive, and point D is 4 volts negative with respect to the reference. Again, all of these voltages are with reference to ground, or point C.

Figure 12 is identical to the circuits shown in Figures 10 and 11, except that the ground point has been changed to point A. Point A is still 12 volts positive with respect to point D; however, it is no longer 12 volts positive with respect to ground. In Figure 12, point D is 12 volts negative, point C is 8 volts negative, and point B is 4 volts negative, all with respect to ground.

The idea of putting the reference point at different places is very common in the design and manufacture of electronic equipment. Depending on the circuit arrangement, the common reference point (ground) may be the most negative point in the circuit (as in Figure 10) or the most positive point in the circuit (as in Figure 12). In some cases it may even be at some in-between point (as in Figure 11).

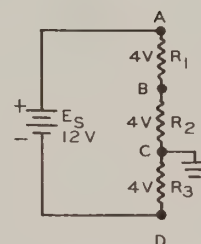


Figure 11

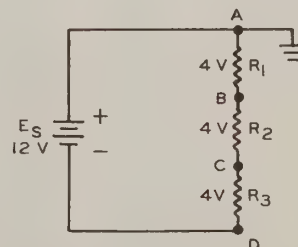


Figure 12

SERIES CIRCUITS

Simple circuits such as the one shown in Figure 13A are easy to analyze. With switch S_1 open, there is no complete path for current. Thus, there is no voltage across R_1 and no current through R_1 . To prove this, we could connect an ammeter and a voltmeter into the circuit as shown in Figure 13B. With S_1 open, there is no complete path, and both meters read zero.

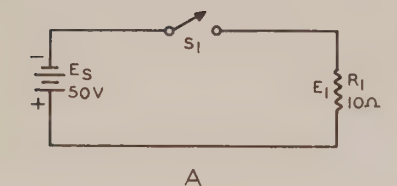
When switch S_1 is closed, as shown in Figure 13C, the circuit is completed and current flows. Starting from the negative terminal of voltage source E_s , current (I_1) flows through switch S_1 , resistor R_1 and ammeter A_1 to the positive terminal of source E_s . With a 50 volt source and 10 ohms of resistance in the circuit, the circuit current is 5 amperes ($50 \div 10$). This is indicated by ammeter A_1 . Also, with 5 amperes of current through resistor R_1 , the voltage across R_1 is 50 volts (as indicated by voltmeter V_1).

In Figure 13C, if we change R_1 from 10 ohms to 50 ohms, the circuit current changes to 1 ampere ($50 \text{ volts} \div 50 \text{ ohms}$). However, with only one resistor in the circuit, the voltage across R_1 would still be equal to the source voltage, or 50 volts. Whenever a single resistor is the only component connected in a circuit with a voltage source, the full source voltage is developed across the resistor. If the resistance of the resistor is changed, the current through it changes but the voltage across it remains equal to the source voltage.

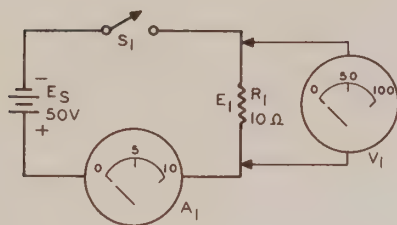
In most electronic equipment, one voltage source supplies electric energy to a number of loads. One way that these loads can be connected is shown in Figure 14A. We call this a **SERIES CIRCUIT** because the components are connected one after another and there is only a single current path through all of the parts. When S_1 is open, there is no complete path for current; therefore, there is no voltage across resistors R_1 and R_2 .

When switch S_1 is closed, the circuit is completed and the conditions of Figure 14B exist. The circuit of Figure 14B is the same as Figure 14A except that we have added an ammeter (A_1) to measure the current through the circuit, and two voltmeters (V_1 and V_2) to measure the voltages across R_1 and R_2 .

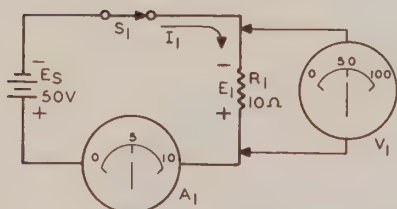
Ammeter (A_1), shown in Figure 14B, indicates 5 amperes of circuit current, while the voltmeters (V_1 and V_2) indicate 25 volts across each of the resistors (R_1 and R_2). These readings enable us to make some conclusions about a series circuit. First, **IN A SERIES CIRCUIT THE VOLTAGES ACROSS THE INDIVIDUAL RESISTORS, WHEN ADDED TO-**



A

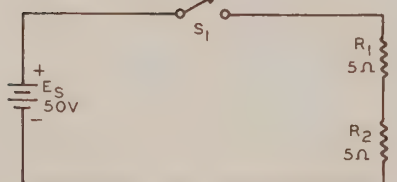


B

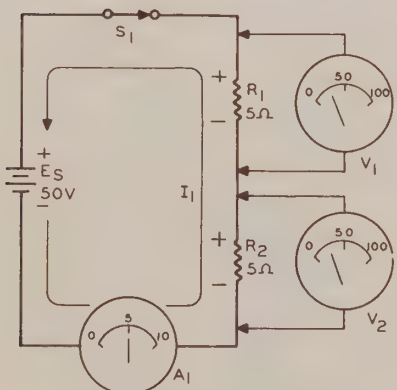


C

Figure 13



A



B

Figure 14

The following Practice Exercise questions cover the subject which you have just studied. It is:

REFERENCE POINTS

13. The voltage produced by a battery is (a) a positive voltage, (b) a negative voltage, (c) a voltage between the positive and negative terminals.
14. In Figure 8, which of the following statements are correct? (a) Point A is positive with reference to point B. (b) Point A is positive with reference to point D. (c) Point D is positive with reference to point C. (d) Point C is positive with reference to point D.
15. In Figure 9, points B and D are common reference points. True or False?
16. A schematic diagram has many points terminated with the ground symbol shown in Figure 9. This means that all of these points probably are (a) connected directly together with hookup wire, (b) connected to the metal chassis, (c) electrically independent of each other.
17. In Figure 10, what is the voltage between points A and B? Between points B and C? Between points A and C?
18. Using ground as a reference in Figure 11, what is the voltage at point D?
19. Ground is always the most negative point in any circuit. True or False?

20. The reference point in a circuit is usually represented in a schematic diagram by a ground symbol or heavy line. True or False?
21. The word "ground" always means "earth ground." True or False?
22. A voltage exists between _____ points.

GETHER, EQUAL THE SOURCE VOLTAGE. Second, THE VOLTAGE ACROSS EACH RESISTOR IS EQUAL TO THE CURRENT THROUGH IT MULTIPLIED BY THE RESISTANCE OF THAT RESISTOR. Thus, the voltage across R_1 is:

$$\begin{aligned} E_1 &= I_1 R_1 \\ &= 5 \times 5 \\ &= 25 \text{ volts.} \end{aligned}$$

Third, THE VOLTAGE ACROSS EACH RESISTOR IN A SERIES CIRCUIT IS DIRECTLY PROPORTIONAL TO THE RESISTANCE OF THAT RESISTOR. That is, the resistor with the largest resistance value



Digital meters can be used to accurately measure voltage, resistance, and current. The digital readout eliminates meter reading errors.

Courtesy Nonlinear Systems Inc.

SERIES AND PARALLEL CIRCUITS

will have the greatest amount of the source voltage. Since R_1 and R_2 are equal in Figure 14, the voltages across them are equal as indicated by V_1 and V_2 .

Finally, we can state a conclusion concerning the total resistance in a series circuit. Ohm's Law states that $R = E/I$. Therefore, the total resistance, R_T is:

$$\begin{aligned} R_T &= \frac{E_s}{I_1} \\ &= \frac{50}{5} \\ &= 10 \text{ ohms.} \end{aligned}$$

With R_1 and R_2 equal to 5 ohms each, we see that **IN A SERIES CIRCUIT THE TOTAL CIRCUIT RESISTANCE, R_T , IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.**

If we chose to do so, we could connect ammeter A_1 between R_1 and R_2 , or on either side of S_1 , or at any place in the circuit and it would indicate 5 amperes of current. **IN A SERIES CIRCUIT THE CURRENT IS THE SAME AT ALL POINTS IN THE CIRCUIT.**

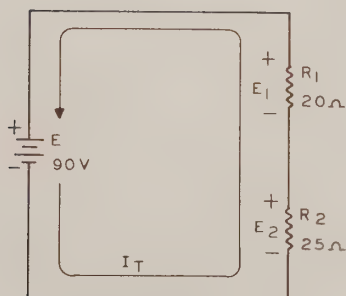


Figure
15

Figure 15 is another example of a series circuit containing two resistors. Since a switch and the various meters are not essential to the operation of the circuit, they have been omitted. Notice that the current is labeled I_T . With only one current in the complete circuit, it must be the total current from the source. It is common practice to label the total current I_T .

To analyze the circuit, first inspect it and determine what is known and what is unknown. In this circuit, we know both the supply voltage and the resistance of each resistor. We don't know the current, the voltage across each resistor or the total resistance. To calculate the voltage across a resistor, you must know the resistance of the resistor and the current through it. Since we don't know the circuit current, I_T , we cannot yet calculate the voltage across the resistors.

We do know that the total resistance, R_T , is equal to the sum of $R_1 + R_2$.
Therefore:

$$R_T = R_1 + R_2$$

$$= 20 + 25$$

$$= 45 \text{ ohms.}$$

Now, knowing R_T , we can calculate the circuit current, I_T , as follows:

$$I_T = \frac{E_s}{R_T}$$

$$= \frac{90}{45}$$

$$= 2 \text{ amperes.}$$

Knowing the circuit current, I_T , and the resistance of each resistor, we can calculate the voltage across each resistor. The voltage across R_1 is:

$$E_1 = I_T R_1$$

$$= 2 \times 20$$

$$= 40 \text{ volts.}$$

The voltage across R_2 is:

$$E_2 = I_T R_2$$

$$= 2 \times 25$$

$$= 50 \text{ volts.}$$

SERIES AND PARALLEL CIRCUITS

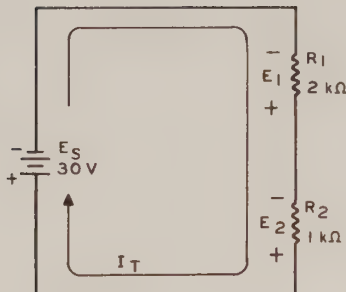


Figure
16

Figure 16 is another example of a series circuit in which we know the source voltage E_s and the resistance of the load resistors R_1 and R_2 . To calculate R_T , the sum of R_1 and R_2 is first obtained:

$$\begin{aligned} R_T &= R_1 + R_2 \\ &= 2000 + 1000 \\ &= 3000 \text{ ohms.} \end{aligned}$$

To calculate I_T , we divide the source voltage by the total resistance:

$$\begin{aligned} I_T &= \frac{E_s}{R_T} \\ &= \frac{30}{3000} \\ &= .01 \text{ ampere or 10 milliamperes.} \end{aligned}$$

The voltage across R_1 is:

$$\begin{aligned} E_1 &= I_T R_1 \\ &= .01 \times 2000 \\ &= 20 \text{ volts.} \end{aligned}$$

The voltage across R_2 is:

$$\begin{aligned} E_2 &= I_T R_2 \\ &= .01 \times 1000 \\ &= 10 \text{ volts.} \end{aligned}$$

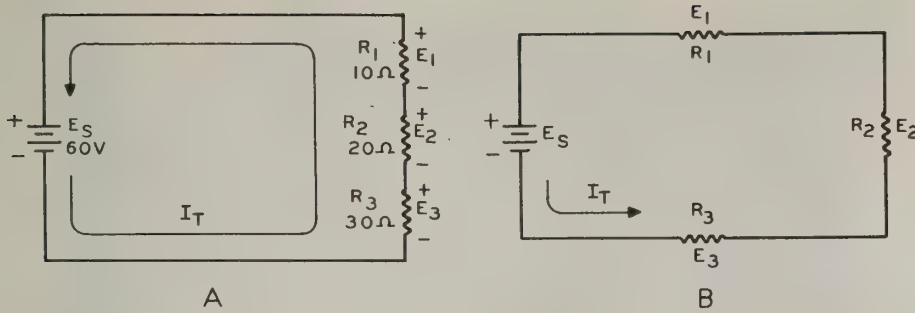


Figure 17

When a series circuit contains more than two resistors, as in Figure 17A, the same general methods are used to analyze the circuit. The total resistance, R_T , is found by adding the resistances of the series resistors as follows:

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ &= 10 + 20 + 30 \\ &= 60 \text{ ohms.} \end{aligned}$$

The total current, I_T , is found by dividing the source voltage by the total resistance:

$$\begin{aligned} I_T &= \frac{E_S}{R_T} \\ &= \frac{60}{60} \\ &= 1 \text{ ampere.} \end{aligned}$$

The voltage across each resistor is directly proportional to its resistance. The resistors' voltages are calculated as follows:

$$\begin{aligned} E_1 &= I_T R_1 = 1 \times 10 = 10 \text{ volts} \\ E_2 &= I_T R_2 = 1 \times 20 = 20 \text{ volts} \\ E_3 &= I_T R_3 = 1 \times 30 = 30 \text{ volts.} \end{aligned}$$

Notice that the sum of the individual series voltages is equal to the source voltage. That is:

$$\begin{aligned}E_s &= E_1 + E_2 + E_3 \\&= 10 + 20 + 30 \\&= 60 \text{ volts.}\end{aligned}$$

The direction of current in Figure 17A is from the negative terminal of the source through R_3 , R_2 and R_1 , and back to the positive terminal of the source as indicated. The plus and minus signs close to the resistors indicate the polarity of the voltage across each resistor. In this particular figure, the top end of each resistor is positive with reference to its bottom end, because the battery polarity is such that the current passes upward through the resistors.

Figure 17B is the same as Figure 17A except that values have not been assigned to the various components. This is done so we can state some general rules that apply to all series circuits. These general rules are:

-
- 1. THE CURRENT IS THE SAME AT ALL POINTS IN A SERIES CIRCUIT.**
 - 2. THE SUM OF THE VOLTAGES ACROSS THE INDIVIDUAL COMPONENTS IN A SERIES CIRCUIT IS EQUAL TO THE SOURCE VOLTAGE.**
 - 3. THE TOTAL RESISTANCE IN A SERIES CIRCUIT IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.**
-

Rule number 2 can be expressed as an equation:

$$E_s = E_1 + E_2 + E_3 \dots + \text{etc.} \quad (1)$$

Rule number 3 can be expressed as an equation:

$$R_T = R_1 + R_2 + R_3 \dots + \text{etc.} \quad (2)$$



The modern color television receiver contains many series and parallel circuits. A thorough understanding of these basic circuits make servicing easier.

Courtesy Motorola Inc.,
Consumer Products Division

The series circuit rules and the methods of analyzing series circuits are the same, regardless of whether the voltage source is ac or dc. Figure 18 is a series circuit similar to Figure 17A except that the voltage source is 120 volts ac rather than 60 volts dc. The total resistance, R_T , is found by adding together the individual resistances:

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ &= 10 + 20 + 30 \\ &= 60 \text{ ohms.} \end{aligned}$$

The circuit current, I_T , is determined by dividing the source voltage by the total resistance:

$$\begin{aligned} I_T &= \frac{E_s}{R_T} \\ &= \frac{120}{60} \\ &= 2 \text{ amperes.} \end{aligned}$$

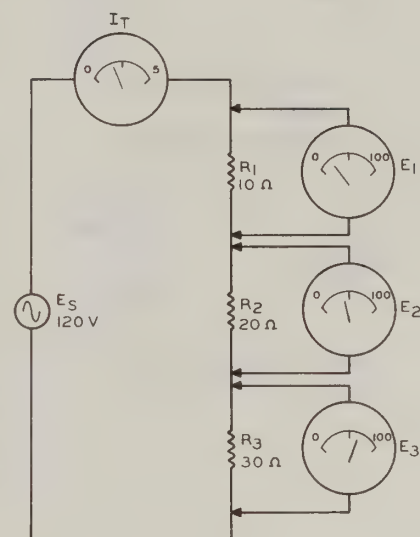


Figure
18

SERIES AND PARALLEL CIRCUITS

The voltage across each resistor is found by multiplying the circuit current by the value of that resistor:

$$E_1 = I_T R_1 = 2 \times 10 = 20 \text{ volts}$$

$$E_2 = I_T R_2 = 2 \times 20 = 40 \text{ volts}$$

$$E_3 = I_T R_3 = 2 \times 30 = 60 \text{ volts.}$$

By adding together the voltages across the individual resistors, we obtain the source voltage (120 volts). The voltages appearing across the resistors are generally referred to as "voltage drops."

The direction of current flow and the voltage polarities are not shown for this ac circuit because they are constantly reversing.

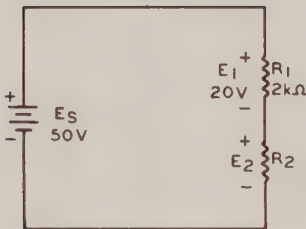


Figure
19

The simple rules for series circuits are used in various ways and at almost every level of electric or electronic work. Assume that you must develop 20 volts across a $2k\Omega$ resistor, using a 50 volt source. Figure 19 shows one way to solve this problem. With a voltage source of 50 volts and only the $2k\Omega$ resistor in the circuit, a 50 volt drop would occur across the $2k\Omega$ resistor. Since we only want 20 volts to be dropped across the $2k\Omega$ resistor, it becomes necessary to add another resistor (R_2 in Figure 19) in series with the $2k\Omega$ resistor (R_1 in Figure 19). If 20 volts is to be dropped across R_1 , there will be 30 volts dropped across R_2 (20 volts + 30 volts = 50 volts = the source voltage).

In order to have 20 volts dropped across the $2k\Omega$ resistor R_1 , the current through it must be:

$$I_T = \frac{E_1}{R_1}$$

$$= \frac{20}{2000}$$

$$= .01 \text{ ampere.}$$

Since the current through R_1 and R_2 must be the same, the current through R_2 is also .01 ampere. Knowing the current through R_2 and the voltage across R_2 , the resistance of R_2 is determined by Ohm's Law as follows:

$$\begin{aligned} R_2 &= \frac{E_2}{I_T} \\ &= \frac{30}{.01} \\ &= 3000 \text{ ohms.} \end{aligned}$$

The same type of analysis is applied to a series circuit where more than two resistors are involved. For example, in Figure 20 it is necessary to determine the resistance of R_2 and the source voltage. To use Ohm's Law, two of the three quantities (I, E, and R) must be known.

Two of these factors are known for R_1 . Knowing that the resistance of R_1 is $10 \text{ k}\Omega$ and the voltage across it (E_1) is 20 volts, the current through it can be found:

$$\begin{aligned} I_T &= \frac{E_1}{R_1} \\ &= \frac{20}{10,000} \\ &= .002 \text{ ampere.} \end{aligned}$$

We also know that the current is the same in all parts of a series circuit. Therefore, the current through R_2 and R_3 is also .002 ampere. Knowing the current through R_2 and the voltage across R_2 , the resistance of R_2 can be determined:

$$\begin{aligned} R_2 &= \frac{E_2}{I_T} \\ &= \frac{60}{.002} \\ &= 30,000 \text{ ohms.} \end{aligned}$$

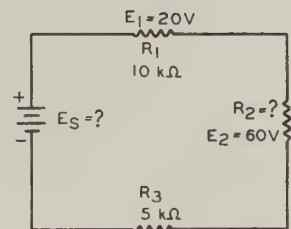


Figure
20

SERIES AND PARALLEL CIRCUITS

The voltage across R_3 is determined as follows:

$$\begin{aligned}E_3 &= I_T R_3 \\&= .002 \times 5000 \\&= 10 \text{ volts.}\end{aligned}$$

Finally, the source voltage, E_s , is determined by taking the sum of the individual voltage drops:

$$\begin{aligned}E_s &= E_1 + E_2 + E_3 \\&= 20 + 60 + 10 \\&= 90 \text{ volts.}\end{aligned}$$

Notice the important relationship between the voltages across the resistors and the resistances of the resistors of the circuit shown in Figure 20. The $5 \text{ k}\Omega$ resistor R_3 has only 10 volts across it. R_1 is $10 \text{ k}\Omega$ (twice the resistance of R_3) and it has twice as much voltage across it as does R_3 . R_2 is $30 \text{ k}\Omega$ (six times the resistance of R_3) and it has six times as much voltage across it as does R_3 .

PARALLEL CIRCUITS

Many practical electric circuits are arranged so that several devices requiring the same amount and type of voltage may be operated from one voltage source. This arrangement also permits one or more of the devices to be turned on and off without affecting the operation of the others. A typical example of this arrangement is the average home or apartment where the electric circuits are wired so that lights, fans, radios and television receivers, and other devices operate from the same voltage source, yet may be turned on and off independently.

To provide for such operation, a **PARALLEL CIRCUIT** is used. As a general definition, a parallel circuit is an arrangement of two or more components, whereby each provides a separate current path from one point to another.

The following Practice Exercise questions cover the subject which you have just studied. It is:

SERIES CIRCUITS

23. In Figure 13B, which of the following statements are true and which are false? (a) The circuit current I_1 is zero. (b) The voltage E_1 across the load resistance, R_1 , is zero. (c) The source voltage E_s is 50 volts.
24. Assume that you have the circuit shown in Figure 13C set up and you change the load resistance, R_1 , from 10 ohms to 5 ohms. What changes occur in the values of I_1 and E_1 ?
25. In the circuit shown in Figure 15, change R_1 from 20 ohms to 65 ohms. What is the total resistance, R_T ? What is the current, I_T ? What are the voltages, E_1 and E_2 ?
26. In the circuit shown in Figure 16, change R_1 to 500 ohms. Calculate R_T , I_T , E_1 and E_2 .
27. In Figure 17A, change R_1 to 70 ohms. What is the total resistance, R_T ? What is the current, I_T ? What are the voltages, E_1 , E_2 and E_3 ?
28. The rules for series circuits apply (a) only when the source voltage is ac, (b) only when the source voltage is dc, (c) when the source voltage is either ac or dc.
29. In Figure 19, the current through R_1 is equal to (a) the source voltage (E_s) divided by the resistance of R_1 , (b) the voltage across R_1 (E_1) divided by the resistance of R_1 , (c) the voltage across R_2 (E_2) divided by the resistance of R_1 .

30. In a series circuit, such as the one shown in Figure 20, the current through R_1 is one-half the current through R_3 . True or False?
31. In a series circuit, such as the one shown in Figure 20, the sum of the voltages across the individual resistors is equal to the source voltage. True or False?
32. In a series circuit, such as the one shown in Figure 20, the voltage across each resistor is inversely proportional to the resistance of each resistor. True or False?

The simplest arrangement of a parallel circuit is shown in Figure 21. For the moment, disregard resistor R_2 . The 50 volt battery and the 10 ohm resistor R_1 are connected as in the basic circuit of Figure 13A. The current through resistor R_1 , which we shall call I_1 , is found the same way as it was in Figure 13A:

$$\begin{aligned} I_1 &= \frac{E_s}{R_1} \\ &= \frac{50}{10} \\ &= 5 \text{ amperes.} \end{aligned}$$

With only one resistor in the circuit (still disregarding R_2), there is only one current path. The total current, I_T , in this case is the same as I_1 .

When a second 10 ohm resistor, R_2 , is connected in parallel with R_1 , as shown in Figure 21, it provides an additional path for current. Since R_2 is connected across the source voltage just as R_1 is, the source voltage forces a current through R_2 which we shall call I_2 . The value of I_2 is calculated as follows:

$$\begin{aligned} I_2 &= \frac{E_s}{R_2} \\ &= \frac{50}{10} \\ &= 5 \text{ amperes.} \end{aligned}$$

With two current paths, the total current supplied by the source is the sum of the two currents:

$$\begin{aligned} I_T &= I_1 + I_2 \\ &= 5 + 5 \\ &= 10 \text{ amperes.} \end{aligned}$$

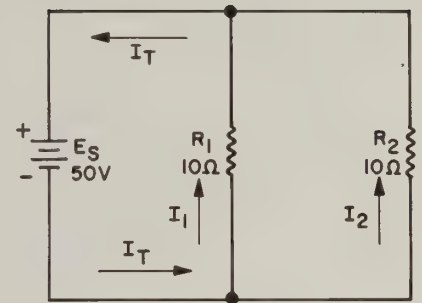


Figure 21

SERIES AND PARALLEL CIRCUITS

By adding R_2 in parallel with R_1 (Figure 21) the total current increases from 5 amperes to 10 amperes. Since the total resistance of an electric circuit is equal to the source voltage divided by the total current, the addition of R_2 causes the total resistance to decrease. The total resistance with both resistors in parallel is only 5 ohms compared to the 10 ohms of either resistor alone.

Each current path of a parallel circuit is called a **BRANCH** of the circuit. Since **THE SOURCE VOLTAGE IS APPLIED ACROSS EACH BRANCH OF A PARALLEL CIRCUIT**, branch current I_1 flows through branch resistance R_1 , and branch current I_2 flows through branch resistance R_2 as shown in Figure 21.

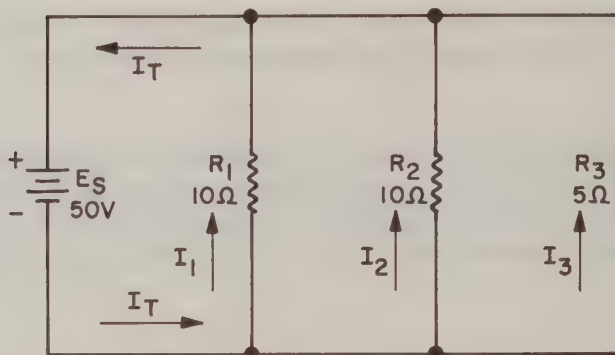


Figure 22

Each time a branch is added to a parallel circuit, the total current increases and the total resistance decreases. In Figure 22, we have added branch resistance R_3 in parallel with branch resistances R_1 and R_2 . The entire source voltage is across R_3 , so branch current I_3 is:

$$I_3 = \frac{E_s}{R_3}$$

$$= \frac{50}{5}$$

$$= 10 \text{ amperes.}$$

We have already found that branch currents I_1 and I_2 are 5 amperes each. The total current supplied by the source is then equal to the sum of the branch currents:

$$\begin{aligned} I_T &= I_1 + I_2 + I_3 \\ &= 5 + 5 + 10 \\ &= 20 \text{ amperes.} \end{aligned}$$

The total resistance in the circuit, R_T , is calculated as follows:

$$\begin{aligned} R_T &= \frac{E_S}{I_T} \\ &= \frac{50}{20} \\ &= 2.5 \text{ ohms.} \end{aligned}$$

Let's analyze our findings of the circuits shown in Figures 21 and 22. Some general rules about parallel circuits can be stated:

-
- 1. THE VOLTAGE ACROSS EACH BRANCH OF A PARALLEL CIRCUIT IS THE SAME AS THE SOURCE VOLTAGE.**
 - 2. THE TOTAL CURRENT IN A PARALLEL CIRCUIT IS EQUAL TO THE SUM OF THE BRANCH CURRENTS.**
 - 3. THE TOTAL RESISTANCE IN A PARALLEL CIRCUIT IS LESS THAN THE RESISTANCE OF ANY BRANCH.**
-

Rule number 2 can be written as an equation:

$$I_T = I_1 + I_2 + I_3 \dots + \text{etc.} \quad (3)$$

Figure 23A is a typical arrangement of various loads connected in parallel across a voltage source. We know that the voltage across each of the branch resistances is the same as the source voltage. To find the current in each

SERIES AND PARALLEL CIRCUITS

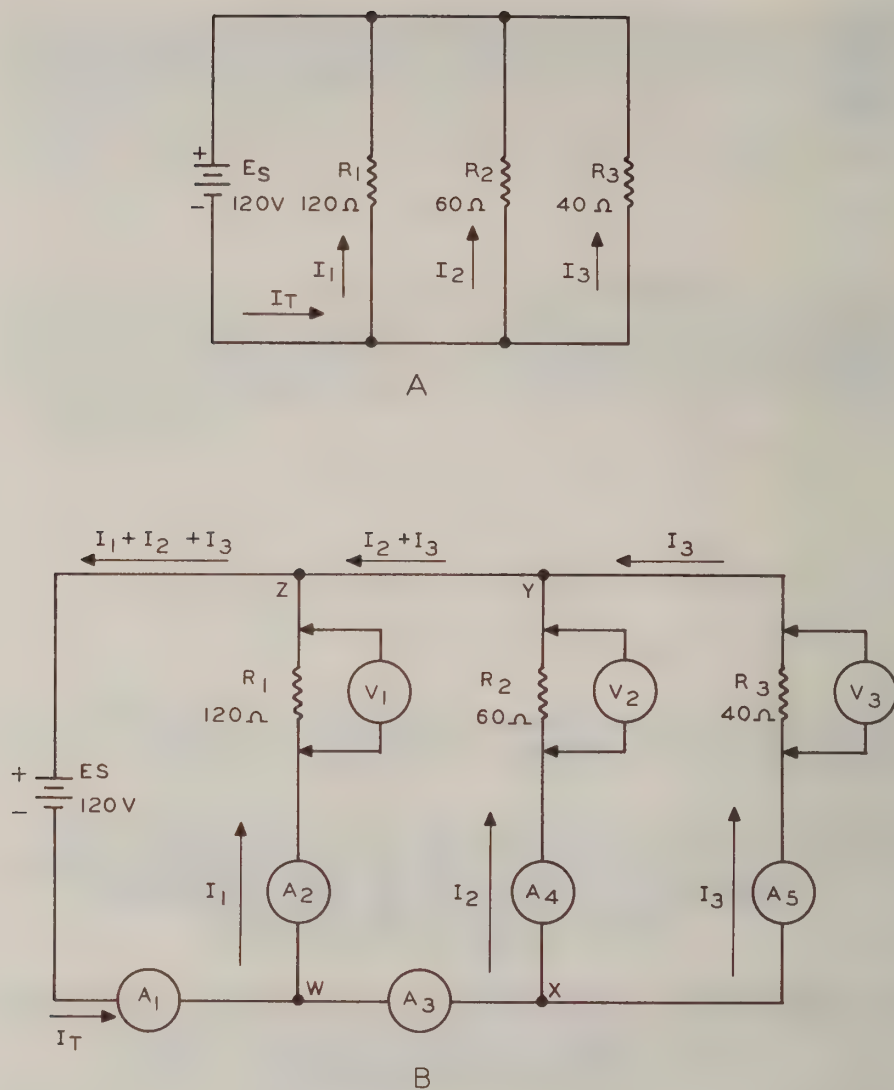


Figure 23

branch, we divide the source voltage by the resistance of each branch as follows:

$$I_1 = \frac{E_s}{R_1} = \frac{120}{120} = 1 \text{ ampere}$$

$$I_2 = \frac{E_s}{R_2} = \frac{120}{60} = 2 \text{ amperes}$$

$$I_3 = \frac{E_s}{R_3} = \frac{120}{40} = 3 \text{ amperes.}$$

We find the total circuit current in Figure 23A as follows:

$$\begin{aligned} I_T &= I_1 + I_2 + I_3 \\ &= 1 + 2 + 3 \\ &= 6 \text{ amperes.} \end{aligned}$$

The total resistance is calculated as follows:

$$\begin{aligned} R_T &= \frac{E_s}{I_T} \\ &= \frac{120}{6} \\ &= 20 \text{ ohms.} \end{aligned}$$

The circuit shown in Figure 23B is the same circuit as shown in Figure 23A, except it has meters connected to it. Voltmeters (V_1 , V_2 , and V_3) are connected across the branch resistances. Each of the voltmeters will indicate 120 volts, since they are connected in parallel with the source voltage.

Ammeter A_1 is connected so that the total current, I_T , must flow through it. From our previous calculations, A_1 will indicate 6 amperes. At junction point W, the current divides, with one ampere flowing through ammeter A_2 and R_1 , and the remainder of the current (5 amperes) continuing on through ammeter A_3 . At junction point X, the current again divides, with 2 amperes flowing through ammeter A_4 and R_2 , and the remaining current (3 amperes) flowing through ammeter A_5 and R_3 .

The 3 amperes of branch current I_3 enter junction point Y and combine with the 2 amperes of branch current I_2 . The sum of branch currents I_2 and I_3 leaves junction point Y and enters junction point Z. The sum of branch currents I_2 and I_3 combines with the 1 ampere of branch current I_1 at junction point Z. The sum of branch currents I_1 , I_2 , and I_3 leaves junction point Z and continues to the positive terminal of the voltage source.

There is a very definite reason for going into detail concerning the current entering a junction point and the current leaving a junction point. In all cases, the current entering a junction point is exactly equal to the current leaving that junction point. It doesn't matter how many paths lead to the junction or how many paths lead away from the junction.

**THE CURRENT ENTERING A JUNCTION AND THE
CURRENT LEAVING A JUNCTION ARE ALWAYS
EQUAL TO EACH OTHER.**

For example, in Figure 23B, the current entering junction point X is 5 amperes. The current leaving is I_2 (2 amperes) and I_3 (3 amperes), the sum of which is also 5 amperes. The current entering junction point Z is 5 amperes from junction point Y and 1 ampere from R_1 . The current leaving junction point Z is the total current of 6 amperes.

Another important relationship of parallel circuits is between the branch currents and the branch resistances. The current through each branch is inversely proportional to the resistance of the branch. In the circuit shown in Figure 23B, the branch with the most resistance (R_1) has the least current, and the branch with the least resistance (R_3) has the most current.

Practically all electrical devices have circuits where the various loads are in parallel. Often it is not convenient to measure the resistance of a device or the current through it. Yet, it may be necessary to know these details. The circuit shown in Figure 24 represents such a situation. The things we know about this circuit are: the source voltage is 120 volts, the total current is 6 amperes, the current through R_1 is .5 ampere, and the resistance of R_2 is 30 ohms. Using Ohm's Law and the basic rules for parallel circuits, we can calculate the remaining quantities in a step-by-step, logical manner.

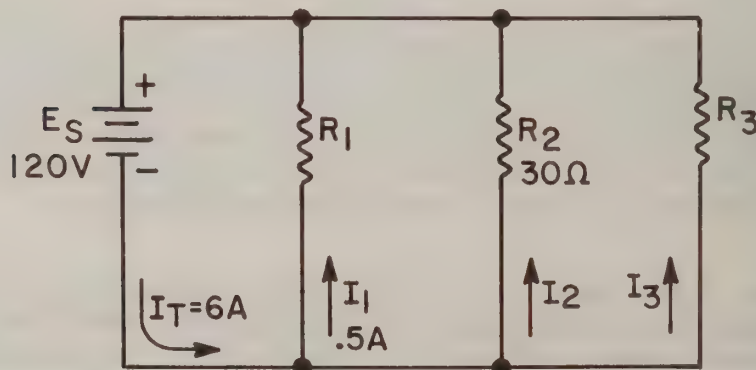


Figure 24

Knowing the source voltage and the resistance of R_2 , the current through R_2 is calculated as follows:

$$\begin{aligned} I_2 &= \frac{E_s}{R_2} \\ &= \frac{120}{30} \\ &= 4 \text{ amperes.} \end{aligned}$$

Since the sum of I_1 (.5 ampere), I_2 (4 amperes), and I_3 must equal I_T (6 amperes), we can now calculate the value of I_3 . The sum of I_1 and I_2 is 4.5 amperes. Subtracting this amount from the total current of 6 amperes leaves 1.5 amperes for I_3 .

Now that we know all of the currents and the source voltage, we can determine R_1 and R_3 by dividing the source voltage by each branch current:

$$R_1 = \frac{E_s}{I_1} = \frac{120}{.5} = 240 \text{ ohms}$$

$$R_3 = \frac{E_s}{I_3} = \frac{120}{1.5} = 80 \text{ ohms.}$$

The total resistance of the circuit is found by dividing the source voltage by the total current:

$$\begin{aligned} R_T &= \frac{E_s}{I_T} \\ &= \frac{120}{6} \\ &= 20 \text{ ohms.} \end{aligned}$$

Notice that the total resistance R_T is less than the smallest branch resistance. This is always the case in parallel circuits.

SERIES AND PARALLEL CIRCUITS

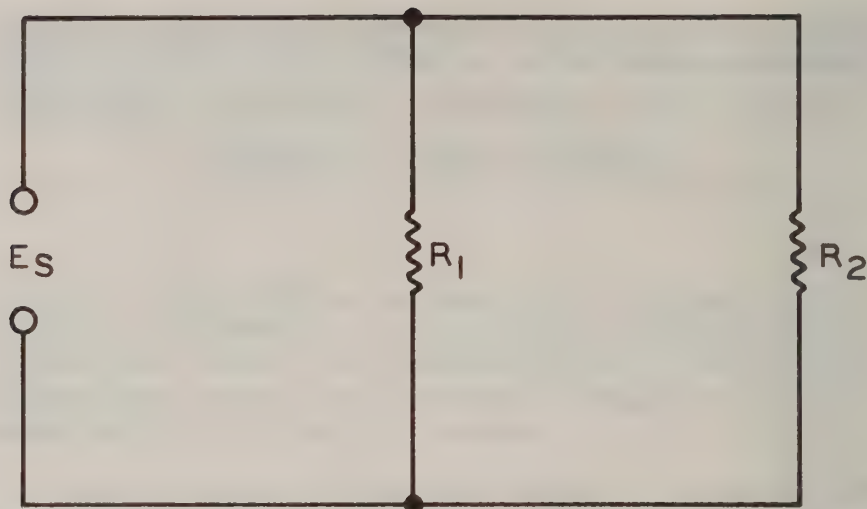


Figure 25

It is often helpful to quickly determine the total resistance of parallel resistors. This is particularly true of two resistances in parallel. Such an arrangement is common in electrical or electronic equipment. Figure 25 shows such a circuit. The total resistance of this circuit, or any circuit having two parallel resistors, can be quickly found by using the following equation:

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \quad (4)$$

In this equation, notice that the two values of resistance are first multiplied together and placed above the division bar. Next, the same values of resistance are added together and placed below the division bar. Because of this arrangement, the equation is usually called the “product over the sum” equation.

To see how this equation works, let's assume E_S is 10 volts, R_1 is 10 ohms and R_2 is 10 ohms. To calculate R_T use the “product over the sum” equation:

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

$$= \frac{10 \times 10}{10 + 10}$$

$$= \frac{100}{20}$$

$$= 5 \text{ ohms.}$$

We can check this answer with the method used earlier. Using our previous methods, we find that the current through each resistor is:

$$I_1 = \frac{E_s}{R_1} = \frac{10}{10} = 1 \text{ ampere.}$$

$$I_2 = \frac{E_s}{R_2} = \frac{10}{10} = 1 \text{ ampere.}$$

The total current I_T is equal to the sum of I_1 and I_2 :

$$\begin{aligned} I_T &= I_1 + I_2 \\ &= 1 + 1 \\ &= 2 \text{ amperes.} \end{aligned}$$

The total resistance R_T is calculated as follows:

$$\begin{aligned} R_T &= \frac{E_s}{I_T} \\ &= \frac{10}{2} \\ &= 5 \text{ ohms.} \end{aligned}$$

Thus, we see that the same value of total resistance for the circuit shown in Figure 25 can be determined by either method.

In the circuit shown in Figure 25, or in any electric circuit, the amount of source voltage does not affect the circuit resistance. Remember, the resistance of a resistor is determined by how it is made and not by the voltage or current in a circuit. Therefore, you can always assume a voltage and use it to calculate the resistance by the longer Ohm's Law method. If you prefer, the "product over the sum" equation can be used when the total resistance in a parallel circuit contains only two resistors.

SERIES AND PARALLEL CIRCUITS

When more than two resistors are connected in parallel, as in Figure 26, the “product over the sum” equation is no longer directly used. Referring back to Figure 22, the total resistance is determined by finding the current in each branch, adding the branch currents together to find the total current, and finally by dividing the source voltage by the total current.

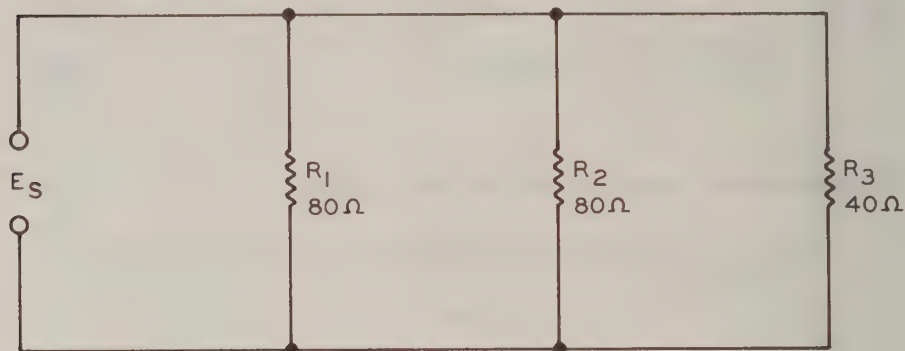


Figure 26

Keep in mind that the source voltage determines the current through a resistor but does not determine the resistance of a resistor. If the source voltage is changed, the current in a circuit changes proportionally but the resistance remains constant. Therefore, in the circuit shown in Figure 26, we can find the total resistance by assuming any value of source voltage. For example, let's assume that E_s is 80 volts. In this case, the assumed currents are calculated as follows:

$$I_1 = \frac{E_s}{R_1} = \frac{80}{80} = 1 \text{ ampere}$$

$$I_2 = \frac{E_s}{R_2} = \frac{80}{80} = 1 \text{ ampere}$$

$$I_3 = \frac{E_s}{R_3} = \frac{80}{40} = 2 \text{ amperes.}$$

The total circuit current is calculated as follows:

$$I_T = I_1 + I_2 + I_3$$

$$= 1 + 1 + 2$$

$$= 4 \text{ amperes.}$$

The total resistance is calculated as follows:

$$\begin{aligned} R_T &= \frac{E_s}{I_T} \\ &= \frac{80}{4} \\ &= 20 \text{ ohms.} \end{aligned}$$

If we had assumed the source voltage to be 240 volts, we would have found the currents and the total resistance as follows:

$$I_1 = \frac{E_s}{R_1} = \frac{240}{80} = 3 \text{ amperes}$$

$$I_2 = \frac{E_s}{R_2} = \frac{240}{80} = 3 \text{ amperes}$$

$$I_3 = \frac{E_s}{R_3} = \frac{240}{40} = 6 \text{ amperes}$$

$$I_T = I_1 + I_2 + I_3 = 3 + 3 + 6 = 12 \text{ amperes.}$$

$$R_T = \frac{E_s}{I_T} = \frac{240}{12} = 20 \text{ ohms.}$$

For either value of assumed source voltage, the total resistance turns out to be 20 ohms.

For convenience, it is best to assume a source voltage which is a multiple of the branch resistances. If we assume a source voltage of 45 volts for the circuit shown in Figure 26, the total resistance is still 20 ohms; however, the arithmetic contains decimals and is more difficult to use.

There is another method for determining the total resistance of a parallel circuit regardless of the number of resistors in the circuit. This method is called the "reciprocal" method of solving parallel circuits and is thoroughly

explained in the Appendix. Whether you use the “reciprocal” method explained in the Appendix, or the voltage and current method explained in the text, is a matter of personal preference. Both methods are good and both methods give identical results.

SUMMARY

Subscripts are small numbers (or letters) used with letter symbols to identify the various components and quantities in electric circuits.

Voltage (potential) is always measured between two points. When a voltage at a certain point is specified as being positive or negative, it is with reference to a previously stated or indicated common reference point in the circuit.

The following general rules apply to series resistance circuits:

1. The current is the same at all points in a series circuit.
2. The sum of the voltages across the individual components in a series circuit is equal to the source voltage.
3. The total resistance in a series circuit is equal to the sum of the individual resistances.

The following general rules apply to parallel resistance circuits:

1. The voltage across each branch of a parallel circuit is the same as the source voltage.
2. The total current in a parallel circuit is equal to the sum of the branch currents.
3. The total resistance in a parallel circuit is less than the resistance of any branch.
4. In a parallel circuit, the current through each branch is inversely proportional to the resistance of the branch.

The following Practice Exercise questions cover the subject which you have just studied. It is:

PARALLEL CIRCUITS

33. In the parallel circuit shown in Figure 21, the voltage across R_2 is (a) one-half the voltage across R_1 , (b) the same as the voltage across R_1 and is equal to E_s .
34. In the parallel circuit shown in Figure 22, the total resistance is (a) the sum of the branch resistances, (b) independent of the branch resistances, (c) less than any of the branch resistances.
35. In the parallel circuit shown in Figure 22, the total current is (a) the sum of the branch currents, (b) divided equally among the branches, (c) less than any of the branch currents.
36. In the parallel circuit shown in Figure 23, the current through each branch (a) is the same as that through the other branches, (b) is inversely proportional to the branch resistance, (c) is directly proportional to the branch resistance.
37. In Figure 23B, how much current is entering junction W? How much is leaving junction W?
38. In Figure 23B, how much current is entering junction Y? How much is leaving junction Y?
39. In the parallel circuit shown in Figure 23, if R_2 is changed to a 120 ohm resistor, what happens to the current through R_2 ? What happens to the total current?
40. In Figure 24, is the total resistance less than or greater than the resistance of R_2 ?

41. In Figure 25, assume that R_1 is 4 ohms and R_2 is 12 ohms. What is the value of R_T ?
42. In Figure 25, assume that both resistors are 20,000 ohms. What is the value of R_T ?
43. In Figure 26, let R_1 be 30 ohms, R_2 be 45 ohms, and R_3 be 90 ohms. What is the value of R_T ?
44. In Figure 26, let the three resistors be 66 ohms each. What is the value of R_T ?

APPENDIX

CALCULATING THE TOTAL RESISTANCE OF PARALLEL CIRCUITS

A rule for finding resistance in parallel circuits, regardless of the number of resistors in the circuit, is: THE TOTAL RESISTANCE OF ANY PARALLEL CIRCUIT IS EQUAL TO THE RECIPROCAL OF THE SUM OF THE RECIPROCALLS OF THE SEPARATE BRANCH RESISTANCES. This rule is stated in the form of an equation as:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots + \text{etc.}}$$

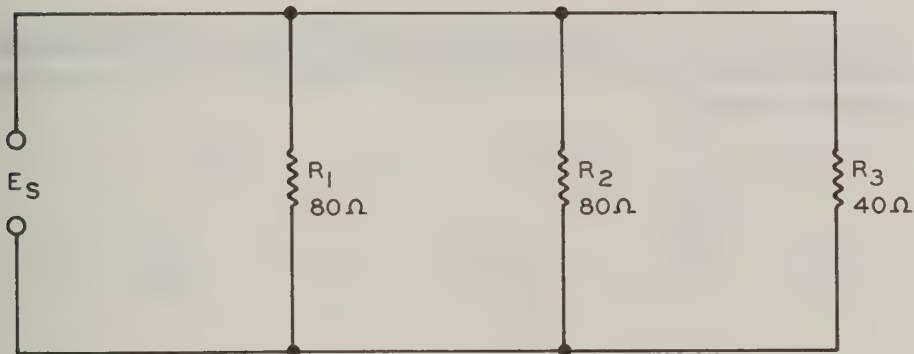


Figure 26

To show the application of this “reciprocal” equation, the resistances of the circuit shown in Figure 26 may be substituted in the equation to calculate the total resistance as follows:

$$R_T = \frac{1}{\frac{1}{80} + \frac{1}{80} + \frac{1}{40}}$$

APPENDIX (Continued)

First, the fractions are changed to a common denominator:

$$R_T = \frac{1}{\frac{1}{80} + \frac{1}{80} + \frac{2}{80}}$$

Next, the fractions are added together and reduced:

$$R_T = \frac{1}{\frac{4}{80}}$$

$$= \frac{1}{\frac{1}{20}}$$

Finally, the number 1 above the main division bar is divided by the fraction below the main division bar. To divide by a fraction, invert the fraction and multiply as follows:

$$R_T = \frac{1}{\frac{1}{20}}$$

$$= 1 \times \frac{20}{1}$$

$$= 20 \text{ ohms.}$$

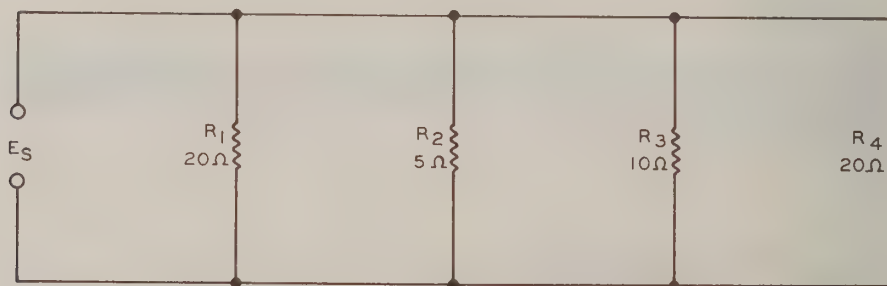


Figure 27

APPENDIX (Continued)

For a second example, the resistances of Figure 27 may be substituted into the "reciprocal" equation as follows:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}$$

$$R_T = \frac{1}{\frac{1}{20} + \frac{1}{5} + \frac{1}{10} + \frac{1}{20}}$$

Again, the fractions are rewritten using a common denominator:

$$R_T = \frac{1}{\frac{1}{20} + \frac{4}{20} + \frac{2}{20} + \frac{1}{20}}$$

Next, the fractions are added together and reduced:

$$R_T = \frac{1}{\frac{8}{20}}$$

$$= \frac{1}{\frac{2}{5}}$$

Finally, invert the fraction below the main division bar and multiply:

$$R_T = \frac{1}{\frac{2}{5}}$$

$$= 1 \times \frac{5}{2}$$

$$= \frac{5}{2}$$

$$= 2.5 \text{ ohms.}$$

IMPORTANT DEFINITIONS

AMMETER—An instrument used to measure the electric current in a circuit.

GROUND—Any point in an electric circuit which is used as a common reference point.

NEGATIVE VOLTAGE—A voltage which is negative with respect to a common reference point.

PARALLEL CIRCUIT—A circuit in which two or more components provide two or more separate current paths from one point to another.

POSITIVE VOLTAGE—A voltage which is positive with respect to a common reference point.

SERIES CIRCUIT—A circuit in which the components are connected one after another so that there is only one current path.

SUBSCRIPTS—Small identifying numbers or letters written slightly to the right of and below the quantity being identified.

SUBSCRIPT NOTATION—An identification system using subscripts.

VOLTMETER—An instrument used to measure the electric pressure, or potential difference, between any two points in a circuit.

ESSENTIAL SYMBOLS AND EQUATIONS

$I_1, I_2, \text{ etc.}$ Current through $R_1, R_2, \text{ etc.}$ (amperes)

I_T Total current (amperes)

$R_1, R_2, \text{ etc.}$ Individual resistors of a circuit (ohms)

R_T Total resistance (ohms)

$E_1, E_2, \text{ etc.}$ Voltage across $R_1, R_2, \text{ etc.}$ (volts)

E_S Source voltage (volts)

$$E_S = E_1 + E_2 + E_3 \dots + \text{etc.} \quad (1)$$

$$R_T = R_1 + R_2 + R_3 \dots + \text{etc.} \quad (2)$$

$$I_T = I_1 + I_2 + I_3 \dots + \text{etc.} \quad (3)$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \quad (4)$$

PRACTICE EXERCISE SOLUTIONS

1. **False—To measure a voltage, a voltmeter is connected across the resistor.**
2. **False—To measure current through a resistor, an ammeter is connected in series with the resistor.**
3. **current**
4. **False—The polarity of the voltage to be measured by a voltmeter must be observed to obtain a correct voltage reading.**
5. **A voltmeter.**
6. **ammeter**
7. **series**
8. **parallel**
9. **False—Subscripts are often used to identify components in an electronic circuit.**
10. **False—The subscript numbers usually have no relationship to the resistance values. The resistance values are determined by the requirements of the circuit.**
11. **(c) all components in a circuit.**
12. **subscript notation**
13. **(c) a voltage between the positive and negative terminals.**
14. **(a) and (d) are both correct.**

PRACTICE EXERCISE SOLUTIONS (Continued)

15. True
16. (b) connected to the metal chassis.
17. 4 volts; 4 volts; 8 volts.
18. Point D is 4 volts negative with respect to ground.
19. False—Other points in a circuit may be negative with respect to ground (more negative than the ground point).
20. True
21. False—The word “ground” does not necessarily mean “earth ground.”
22. two
23. All are true.—With Switch S_1 open, the circuit is incomplete so there is no current through R_1 and no voltage across R_1 . The battery voltage, however, remains 50 volts whether S_1 is open or closed.
24. I_1 increases from 5 amperes to 10 amperes but E_1 remains at 50 volts.
25. $R_T = 90$ ohms; $I_T = 1$ amp; $E_1 = 65$ volts; $E_2 = 25$ volts. These values are found as follows:

$$R_T = R_1 + R_2 = 65 + 25 = 90 \text{ ohms.}$$

$$I_T = \frac{E_S}{R_T} = \frac{90}{90} = 1 \text{ amp}$$

$$E_1 = I_T R_1 = 1 \times 65 = 65 \text{ volts}$$

$$E_2 = I_T R_2 = 1 \times 25 = 25 \text{ volts.}$$

PRACTICE EXERCISE SOLUTIONS (Continued)

26. $R_T = 1500$ ohms; $I_T = 20$ mA; $E_1 = 10$ volts; $E_2 = 20$ volts. These values are found as follows:

$$R_T = R_1 + R_2 = 500 + 1000 = 1500 \text{ ohms}$$

$$I_T = \frac{E_S}{R_T} = \frac{30}{1500} = .02 \text{ ampere or } 20 \text{ mA}$$

$$E_1 = I_T R_1 = .02 \times 500 = 10 \text{ volts}$$

$$E_2 = I_T R_2 = .02 \times 1000 = 20 \text{ volts.}$$

27. $R_T = 120$ ohms; $I_T = .5$ A; $E_1 = 35$ volts; $E_2 = 10$ volts; $E_3 = 15$ volts. These values are found as follows:

$$R_T = R_1 + R_2 + R_3 = 70 + 20 + 30 = 120 \text{ ohms}$$

$$I_T = \frac{E_S}{R_T} = \frac{60}{120} = .5 \text{ ampere}$$

$$E_1 = I_T R_1 = .5 \times 70 = 35 \text{ volts}$$

$$E_2 = I_T R_2 = .5 \times 20 = 10 \text{ volts}$$

$$E_3 = I_T R_2 = .5 \times 30 = 15 \text{ volts.}$$

28. (c) when the source voltage is either ac or dc.
29. (b) the voltage across R_1 (E_1) divided by the resistance of R_1 .—The current through any resistor is always equal to the voltage across it divided by its resistance.
30. False—In a series circuit, the current is the same in all parts of the circuit.
31. True—In a series circuit, the source voltage divides between the individual components in proportion to their resistance values.

PRACTICE EXERCISE SOLUTIONS (Continued)

32. False—In a series circuit, the voltage across each resistor is directly proportional to the resistance of each resistor.
33. (b) the same as the voltage across R_1 and is equal to E_s .—In a parallel circuit, the source voltage is applied across each branch of that parallel circuit.
34. (c) less than any of the branch resistances.
35. (a) the sum of the branch currents.
36. (b) is inversely proportional to the branch resistance.
37. 6 amperes entering and leaving.—The current entering a junction and the current leaving the same junction are equal.
38. 5 amperes entering and leaving.—The current entering a junction and the current leaving a junction are equal.
39. Both the current through R_2 and the total current decrease.—Increasing the resistance of a branch decreases the current through that branch. When the current through R_2 decreases, the total current also decreases.
40. The total resistance is less than the resistance of R_2 .—In a parallel circuit, R_T is less than the resistance of any branch.
41. 3 ohms.

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

$$= \frac{4 \times 12}{4 + 12}$$

$$= \frac{48}{16}$$

$$= 3 \text{ ohms.}$$

PRACTICE EXERCISE SOLUTIONS (Continued)

42. 10,000 ohms.

$$\begin{aligned} R_T &= \frac{R_1 R_2}{R_1 + R_2} \\ &= \frac{20,000 \times 20,000}{20,000 + 20,000} \\ &= \frac{400,000,000}{40,000} \\ &= 10,000 \text{ ohms.} \end{aligned}$$

Notice that, when two resistors of equal resistance are connected in parallel, the total resistance is equal to one-half the resistance of either resistor.

43. 15 ohms.—Assume a source voltage of 90 volts. Solve for the branch currents, the total current and the total resistance as follows:

$$I_1 = \frac{E_s}{R_1} = \frac{90}{30} = 3 \text{ amperes}$$

$$I_2 = \frac{E_s}{R_2} = \frac{90}{45} = 2 \text{ amperes}$$

$$I_3 = \frac{E_s}{R_3} = \frac{90}{90} = 1 \text{ ampere}$$

$$I_T = I_1 + I_2 + I_3 = 3 + 2 + 1 = 6 \text{ amperes}$$

$$R_T = \frac{E_s}{I_T} = \frac{90}{6} = 15 \text{ ohms.}$$

Remember, any source voltage can be assumed. The circuit currents will change but the resistance will be the same.

PRACTICE EXERCISE SOLUTIONS (Continued)

44. 22 ohms.—Assume a source voltage of 66 volts. Solve for the branch currents, the total current and the total resistance as follows:

$$I_1 = \frac{E_s}{R_1} = \frac{66}{66} = 1 \text{ ampere}$$

$$I_2 = \frac{E_s}{R_2} = \frac{66}{66} = 1 \text{ ampere}$$

$$I_3 = \frac{E_s}{R_3} = \frac{66}{66} = 1 \text{ ampere}$$

$$I_T = I_1 + I_2 + I_3 = 1 + 1 + 1 = 3 \text{ amperes}$$

$$R_T = \frac{E_s}{I_T} = \frac{66}{3} = 22 \text{ ohms.}$$

Whenever all of the resistors in a parallel circuit are the same resistance, the total resistance of the circuit is equal to the resistance of one resistor divided by the number of resistors.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE
1010A

Example:

A	☐
B	☒
C	☐
D	☐

A young cat is called a

A. pup. B. kitten. C. cub. D. chick.

1. A ☐ When connecting a voltmeter into a dc circuit,
 B ☐ (A) polarity is not important. (B) the meter is connected in series with the circuit.
 C ☐ (C) the voltmeter is connected in parallel. (D) the negative meter lead connects
 D ☐ to the most positive point in the circuit.
2. A ☐ When a voltage is indicated at some point in a circuit, the actual meaning is
 B ☐ (A) the voltage between that point and a reference point. (B) the voltage WITH-
 C ☐ OUT reference to any other point. (C) always the voltage between that point and
 D ☐ the positive terminal of the source. (D) the voltage between that point and ANY
 other point.
3. A ☐ In a series circuit, the current is
 B ☐ (A) greater in the high resistance components. (B) the same in all parts of the
 C ☐ circuit. (C) the sum of the branch currents. (D) greater in the low resistance
 D ☐ components.
4. A ☐ In a parallel circuit, the current
 B ☐ (A) is greatest in the highest resistance branch. (B) in each branch is added to-
 C ☐ gether to determine the total current. (C) is the same in all parts of the circuit.
 D ☐ (D) is inversely proportional to the source voltage.
5. A ☐ In a SERIES circuit, the source VOLTAGE
 B ☐ (A) is equal to the sum of the voltages across the components. (B) is applied
 C ☐ DIRECTLY across each component. (C) forces a DIFFERENT amount of cur-
 D ☐ rent through each component. (D) is ALWAYS divided equally among all com-
 ponents.
6. A ☐ In a PARALLEL circuit, the source VOLTAGE
 B ☐ (A) is equal to the SUM of the voltages across the components. (B) appears
 C ☐ across each branch. (C) is inversely proportional to the resistance of each branch.
 D ☐ (D) always forces the SAME amount of current through each branch.
7. A ☐ In a series circuit, the total resistance
 B ☐ (A) is less than the resistance of any individual resistor. (B) is inversely propor-
 C ☐ tional to the amount of source voltage. (C) is equal to the sum of the individual
 D ☐ resistances. (D) increases when the circuit current increases.
8. A ☐ In a parallel circuit, the total resistance
 B ☐ (A) is less than the resistance of any branch. (B) is equal to the sum of the
 C ☐ branch resistances. (C) is greater than the resistance of any branch resistor. (D)
 D ☐ increases when the circuit current increases.
9. A ☐ In Figure 16, if the source voltage is increased from 30 volts to 60 volts,
 B ☐ (A) the total resistance reduces to one third its original value. (B) the voltages
 C ☐ across R_1 and R_2 double. (C) the current through R_1 doubles and the current
 D ☐ through R_2 is cut in half. (D) there is no change in the circuit current.
10. A ☐ In Figure 23A, if R_3 is INCREASED from 40 ohms to 120 ohms,
 B ☐ (A) the voltage across R_3 decreases. (B) the current through R_2 decreases. (C)
 C ☐ the current through R_3 remains constant. (D) the current through R_3 and the
 D ☐ total current decrease.

ELECTRIC POWER

1013

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The Dresden Nuclear Power Station near Joliet, Illinois is capable of providing 180,000 kilowatts of electric power. A 190-foot-diameter sphere houses the nuclear reactor and steam generators.

Courtesy Commonwealth Edison Company.

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*Learning is wealth to the poor, an honor to the rich, an aid
to the young, and a support and comfort to the aged.*

—Lavater

ELECTRIC POWER

Electric power is one of the most important quantities that we deal with in the study of electricity and electronics. In this lesson we will explain several practical ways of determining power.

ENERGY AND POWER

In a complete electronic circuit, the electromotive force “pushes” electrons into motion. When electrons are forced into motion, they have kinetic energy or the energy of motion. Electric energy is measured in terms of a unit called a **JOULE**. Electrical energy thus involves both a voltage and a quantity of electrons. These two factors can be put in the form of an equation to specify the amount of energy in an electric circuit:

$$E_n = EQ \quad (1)$$

where: E_n is the energy in joules,

E is the electric potential in volts, and

Q is the number of coulombs of electrons (one coulomb = 6.28×10^{18} electrons).

Thus, one joule of electric energy is developed when an electric potential of one volt forces one coulomb of electrons through a circuit.

The terms energy and power are often confused. **POWER IS THE RATE OF ENERGY EXPENDED.** Thus, **ELECTRIC POWER** is the amount of electric energy produced or used in a given length of time. The relation between energy and power is like the relationship between distance and speed. Distance can be measured in “miles” and speed in “miles per hour.” Miles and miles per hour are not the same unit.

An equation for electric power can be developed from Equation 1. Power is energy per unit of time and is measured in **WATTS**. Using the second as the unit of time, power in an electric circuit is equal to:

$$P = \frac{E_n}{T} = \frac{EQ}{T} \quad (2)$$

where: P is the power in watts,

E is the electric pressure in volts,

Q is the number of coulombs of electrons, and

T is the time in seconds.

Thus, one watt equals one volt times one coulomb per second. Since one coulomb per second is equal to an ampere, Equation 2 can be rewritten in a more convenient form as shown below:

$$P = EI \quad (3)$$

where: **P** is the power in watts,
E is the electric pressure in volts, and
I is the current in amperes.

The basic unit of electric power, the **WATT**, is equal to an electric pressure of one volt times a current of one ampere. Since power is energy per unit of time, we can also state that a joule of energy is a watt second.

POWER MEASUREMENT AND POWER DISSIPATION

Now let's find the power being used in the simple circuit shown in Figure 1. In this circuit we have battery E_s forcing current through load resistor R_1 . Since power is found by multiplying the current by the voltage, we must determine the circuit current before we can find the power.

In the circuit of Figure 1, the battery supplies a voltage of 100 volts. Current through resistor R_1 is found by dividing the voltage across load R_1 (100 volts) by its resistance (50 ohms). The current is 2 amperes. Once we have the current and the voltage, we can find the power. Power is equal to the voltage times the current. In Figure 1 the power is equal to 100 volts times 2 amperes. The result of this multiplication gives us 200 watts.

You may have wondered why some batteries can provide heavy duty service, as in starting your car, while other batteries with the same voltage rating are good only for light duty service, as in operating a pocket radio. The answer lies in the power ratings of the batteries. Let's apply what we have learned about power so far to see why you can't use the battery from your transistor radio to start your car.

Consider a 6 volt automobile battery with a maximum current of 500 amperes. Its maximum power output is $6 \times 500 = 3000$ watts. A 6 volt battery used in a transistor radio may have a maximum current of 20 mA. Its maximum

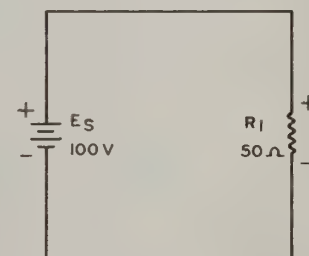


Figure
1



The power consumption of an electric appliance can be determined by measuring the source voltage and circuit current. This clip-on ammeter provides a means of measuring circuit current without breaking the circuit to insert an ammeter.

Courtesy Amprobe Instrument Company

power output is only $6 \times .02 = .12$ watt. Thus, even though the two batteries supply the same voltage, the difference in current capacity makes the automobile battery by far the more "powerful" of the two.

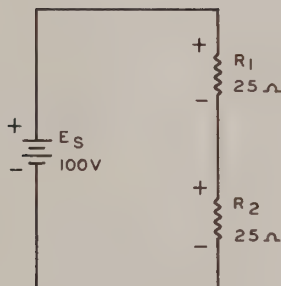


Figure
2

Assume you have a circuit that has more than one device requiring the use of power. Use the same method to find the power dissipated by these devices as you do when there is only one device. Just multiply the voltage by the current. Finding the power used in a series or parallel circuit gives you a good chance to apply some of the things you have already learned about electric circuits.

For example, in the circuit shown in Figure 2 there are two 25 ohm resistors connected in series rather than one 50 ohm resistor shown in Figure 1. To find the power dissipated in Figure 2, you must find the total resistance and then the circuit current.

You find the total circuit resistance in Figure 2 by adding resistances R_1 and R_2 : $25 \text{ ohms} + 25 \text{ ohms} = 50 \text{ ohms}$. Circuit current is found as before: by dividing the circuit voltage by the total circuit resistance. Thus, circuit current is $100/50 = 2$ amperes. In Figure 2 the total power is equal to the circuit voltage, 100 volts, multiplied by the circuit current, 2 amperes: $100 \times 2 = 200$ watts. This amount of power is being produced by the battery and dissipated by resistors R_1 and R_2 .

Notice that the battery voltage E_s is the same in both Figure 1 and Figure 2. The circuit current is also the same in both circuits. Therefore, the total power is the same for both circuits. However, there is one important difference between the two circuits. In Figure 1 the entire 200 watts is being dissipated by R_1 . In Figure 2 the 200 watts of power is divided between R_1 and R_2 .

You can use the same general method to find the power dissipated by either resistor. Remember, **POWER IS FOUND BY MULTIPLYING VOLTAGE BY CURRENT**. However, here you have to be a little careful. The voltage to use is the voltage across the resistor whose power you are determining. Also, the current used is the current through that particular resistor.

With these points in mind, let's find the power dissipated by each resistor in Figure 2. We have already determined that the circuit current in Figure 2 is 2 amperes. Since this is a series circuit, the same current (2 amperes) must flow through each resistor. According to Ohm's Law, the voltage across a resistor can be determined by multiplying the current through it by its resistance value. In this case, the voltage across R_1 is equal to the current, 2 amperes, times its resistance, 25 ohms, which equals 50 volts.

Now that both the voltage across R_1 and the current through it are known, you can determine the power it dissipates. Simply multiply the voltage across R_1 (50 volts) by the current through it (2 amperes): $50 \times 2 = 100$ watts.

You can find the power dissipated by R_2 using the same method. Knowing the current through R_2 , you multiply it by the resistance value of R_2 to find the voltage across R_2 . Then multiply the voltage across R_2 by the current through R_2 to find the power it dissipates. Since the resistance of R_2 is the same as that of R_1 and the current is the same, each resistor dissipates the same amount of power, 100 watts.

The total power dissipated in a series circuit is equal to the sum of the powers dissipated by the individual components. Therefore, all that you

have to do to find the total power dissipated by the circuit of Figure 2 is to add the power dissipated by R_1 to that of R_2 . Since we said that each resistor dissipates 100 watts, the total power is 200 watts. Using the symbol P_T to represent the total power dissipated, P_1 to represent the power dissipated by R_1 , and P_2 to represent the power dissipated by R_2 , we can write this formula using symbols:

$$P_T = P_1 + P_2 + . . . \text{etc.} \quad (4)$$

The above formula applies to any series circuit. For example, if there were three resistors, you would add together the values of P_1 , P_2 and P_3 .

The resistance of a load used in an electronic system is sometimes hard to measure. A vacuum tube, for example, has a heating element whose resistance increases considerably as its temperature increases. Because of this, the cold resistance of the element cannot be used to determine the current that flows in the circuit when the tube is operating normally.

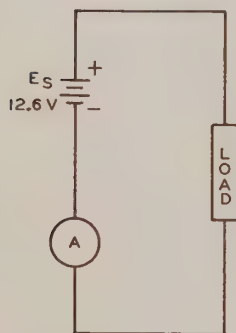


Figure
3

A method used to determine the power in this type of a circuit is shown in Figure 3. In this circuit, a block labeled **LOAD** represents a tube heating element. The source voltage is 12.6 volts. Since we can't calculate the circuit current in this circuit, we will measure it. Ammeter **A** is connected in series with the load so that the load current passes through the meter.

Assume that the ammeter indicates a current of .6 ampere. We now know the voltage across the load and the current through it. To find the power dissipated by the load, we simply multiply these values together: 12.6 volts $\times$.6 ampere = 7.56 watts.

We can also determine the resistance of the heating element during normal operation. For this we will use a form of Ohm's Law. The resistance of the heating element is equal to the voltage across it divided by the current through it ($R = E/I$). The load resistance is equal to 12.6 volts divided by .6 ampere, which is 21 ohms.

Remember, the watt is the basic unit of measurement of electric power. It often happens that the power dissipated in a load is less than 1 watt. Therefore, there are two smaller units of power which can be used in these cases. One unit is the **MILLIWATT (mW)**. It is one-thousandth of a watt. The other unit, the **MICROWATT (μ W)**, is one-millionth of a watt. The following list is a handy comparison of these units:

$$1 \text{ watt} = 1000 \text{ milliwatts}$$

$$1 \text{ watt} = 1,000,000 \text{ microwatts}$$

$$1 \text{ milliwatt} = .001 \text{ watt}$$

$$1 \text{ microwatt} = .000001 \text{ watt.}$$

To get some practice using these units, we will examine the circuit shown in Figure 4. The first step toward finding the total power dissipated is to find the total resistance. The total resistance is equal to the sum of the series resistors R_1 and R_2 . Therefore, the total resistance equals $1 \text{ k}\Omega + 2 \text{ k}\Omega$, or $3 \text{ k}\Omega$. This can also be written as 3000Ω .

The total current, I_T , is found by dividing the source voltage, E_s , by the total resistance, R_T . In our example the total current is equal to $30/3000$, which is .01 ampere or 10 milliamperes.

Knowing the circuit current, we can determine the voltages across R_1 and R_2 . Simply multiply the circuit current by the resistance values. E_1 , the voltage across R_1 , is equal to $.01 \times 1000 = 10$ volts. E_2 , the voltage across R_2 , is equal to $.01 \times 2000 = 20$ volts. This points out the fact that with equal currents through several resistors, the resistor with the greatest resistance value will have the greatest voltage across it.

The next step is to find the power dissipated by each resistor of Figure 4. The power dissipated by R_1 is equal to the voltage across it, E_1 , multiplied by the circuit current, I_T . Since $E_1 = 10$ volts and $I_T = .01$ ampere, the power used by R_1 is $10 \times .01 = .1$ watt. For convenience you might want to write this as 100 milliwatts instead of .1 watt.

The power dissipated by R_2 is found the same way. It is equal to $E_2 \times I_T$. Since E_2 equals 20 volts and I_T equals .01 ampere, the power dissipated by R_2 is $20 \times .01 = .2$ watt. If you prefer, you can write this as 200 milliwatts.

Total power dissipated by P_T in the circuit shown in Figure 4 is equal to the sum of the individual powers, P_1 and P_2 . Therefore, $P_T = 100 \text{ milliwatts} + 200 \text{ milliwatts} = 300 \text{ milliwatts}$ or .3 watt.

Remember, when you change from watts to milliwatts, you have to move the decimal point three places to the right. This is the same as multiplying by

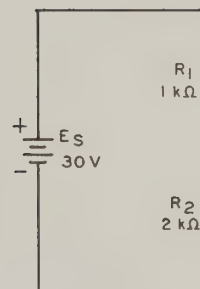
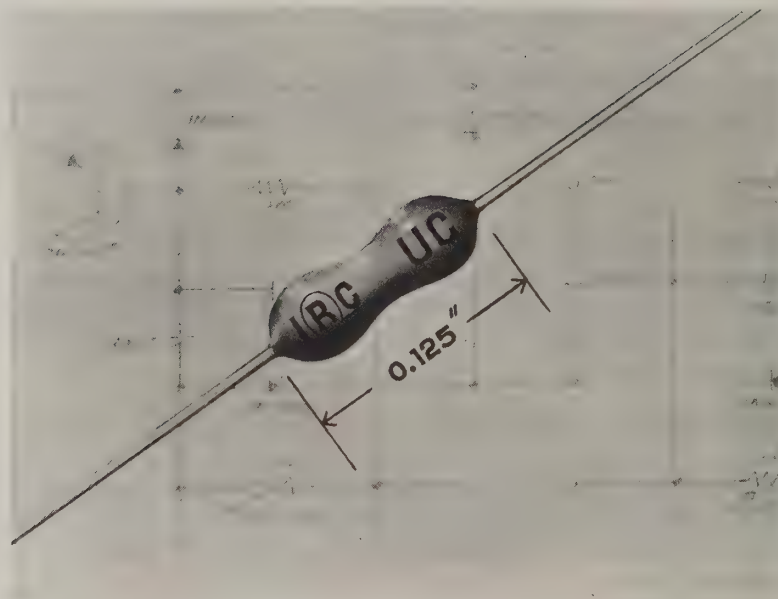


Figure
4



This microminiature resistor is designed for microminiature circuits such as those found in aerospace electronic equipment. It has a power rating of 1/20 watt.

Courtesy IRC Division of TRW Inc.

1000. To change from milliwatts to watts, you have to move the decimal point three places to the left. This is the same as dividing by 1000.

Another method of determining the total power of the circuit shown in Figure 4 is to multiply the total voltage, E_s , by the total current, I_T : $P_T = E_s \times I_T$. Therefore, total power equals $30 \times .01 = .3$ watt. Both methods yield the same answer.

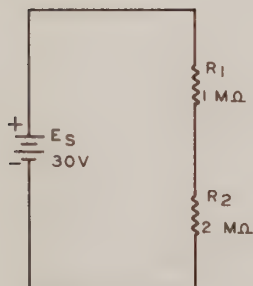


Figure
5

Let's see what happens to the dissipated circuit if the values of R_1 and R_2 in Figure 4 are increased as shown in Figure 5. The total resistance is again the sum of the individual resistances, R_1 and R_2 . Since $R_1 = 1 \text{ M}\Omega$ and $R_2 = 2 \text{ M}\Omega$, $R_T = 3 \text{ M}\Omega$ or 3,000,000 Ω .

Total current, I_T , is equal to the source voltages, E_s , divided by the total resistance, R_T . Total current equals $30/3,000,000 = .00001$ ampere or 10 microamperes. The voltage across R_1 is equal to the current through it times its resistance. Therefore, $E_1 = .00001 \times 1,000,000 = 10$ volts. The voltage across R_2 is found in the same way: $E_2 = .00001 \times 2,000,000 = 20$ volts.

We now have the information necessary to determine the power dissipated in the circuit shown in Figure 5. The power dissipated by R_1 is equal to the voltage across it times the current through it: $P_1 = 10 \times .00001 = .0001$ watt or 100 microwatts. The power dissipated by R_2 is equal to the voltage across it times the current through it: $P_2 = 20 \times .00001 = .0002$ watt or 200 microwatts.

There are two ways of finding the total power dissipated by the circuit shown in Figure 5. One way is to add the individual power values: 100 microwatts plus 200 microwatts equals 300 microwatts. The other way is to multiply the source voltage, E_s , by the total current, I_T : $30 \times .00001 = .0003$ watt or 300 microwatts. Note that the increase of circuit resistance caused a decrease in circuit current and thus a decrease in the power dissipated by the circuit.

Remember, to change watts to microwatts, you move the decimal point six places to the right. This is the same as multiplying by 1,000,000. To change microwatts to watts, you move the decimal point six places to the left. This is the same as dividing by 1,000,000.

In series circuits, such as those shown in Figures 2, 4 and 5, the total circuit power dissipated is equal to the sum of the powers dissipated in all of the individual components. To see how the total power is determined in a parallel circuit, let's examine Figure 6.

The current through each resistor can be found by dividing the source voltage by the resistance value of the resistor. The current through R_1 is

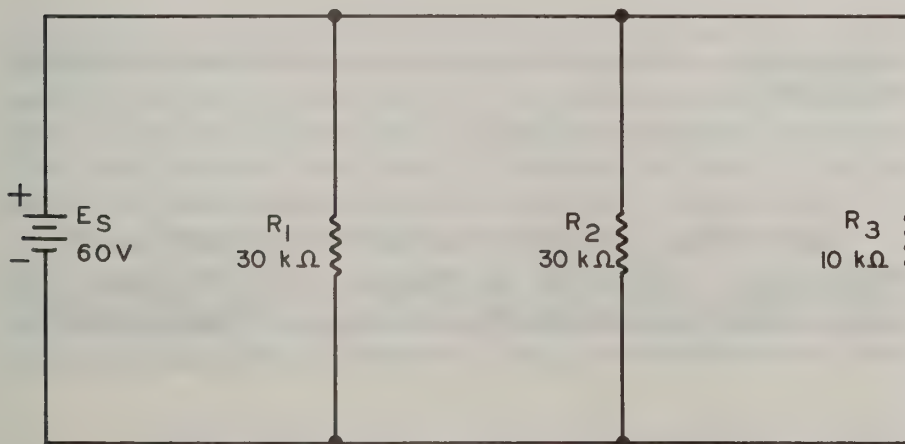


Figure 6

equal to the source voltage (60 volts) divided by the resistance of R_1 (30,000 ohms): $I_1 = 60/30,000 = .002$ ampere. The current through R_2 is: $60/30,000 = .002$ ampere. The current through R_3 is: $60/10,000 = .006$ ampere. To calculate the total circuit current, just add up the individual branch currents. Total current, I_T , is equal to $.002 + .002 + .006 = .01$ ampere.

The power in each branch can be calculated by multiplying the source voltage by the current through the branch. Again, we are using Equation 3 which states that $P = EI$. In the branch containing R_1 , the power is $60 \times .002 = .12$ watt or 120 milliwatts. The power in the branch containing R_2 also is $60 \times .002 = .12$ watt or 120 milliwatts. The power in the R_3 branch is $60 \times .006 = .36$ watt or 360 milliwatts.

We can find the total power dissipated in the circuit of Figure 6 by either of the two methods we used before. To refresh your memory we will use them both again. One method is to multiply the source voltage by the total circuit current. In Figure 6 the source voltage is 60 volts and we determined the total current to be .01 ampere. Therefore, the total power is $60 \times .01 = .6$ watt or 600 milliwatts.

The other method is simply to add the powers dissipated in the individual branches. Total power is then $.12 \text{ watt} + .12 \text{ watt} + .36 \text{ watt} = .6 \text{ watt}$ or 600 milliwatts. Either method should give you the same answer. This means that you can use one method to check the answer you obtained using the other method.

Looking back at what we have learned so far, we can make the following general rule:

THE TOTAL POWER IN BOTH SERIES AND PARALLEL CIRCUITS IS EQUAL TO THE SUM OF THE POWER DISSIPATED IN ALL COMPONENTS.

Although the basic equation for determining power is $P = EI$, there are other equations which may be used to save time and work. The second and

third equations are developed from the basic equation. The second power equation which can be used is written as follows:

$$P = I^2 R. \quad (5)$$

This equation may be used when the current and resistance are known but the voltage would have to be calculated. The I^2 in this equation means that current, I , must be multiplied by itself (squared). To show this condition, the number 2 is placed at the upper right of the letter I . Thus, the equation is read as: "Power equals Current squared times Resistance" or "P equals I squared R."

This power equation is very useful because it states the relationship between power, current and resistance. In the circuit of Figure 7, the only known quantities are the total current and the resistance of R_2 . Without knowing anything else, we can determine the power dissipated by R_2 . According to Equation 5, to find the power dissipated by R_2 , all we do is square the current value and multiply this result by the resistance value of R_2 :

$$P_2 = 2^2 \times 25 = (2 \times 2) \times 25 = 4 \times 25 = 100 \text{ watts.}$$

A third equation may also be used for determining the power in a circuit or component. It includes the voltage across the component or source and the resistance of the component or circuit. This equation is written as follows:

$$P = \frac{E^2}{R} \quad (6)$$

To find power using this equation, the voltage is first multiplied by itself (squared). The result is then divided by the resistance, and the equation is read as "P equals E squared over R." This equation is useful because it shows the relationship between power, voltage and resistance. You can use it to simplify problems where voltage and resistance are known but current would have to be calculated.

Equation 6 simplifies finding the power of R_1 in Figure 8. Here we know only the resistance of R_1 and the voltage across it. The power dissipated across the resistor is $(20 \times 20)/10 = 40$ watts.

Any of the power equations may be rearranged by following the rules of mathematics. The rearranged form of an equation may make it easier to

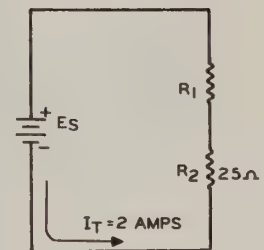


Figure
7

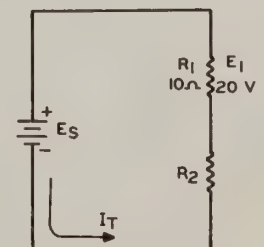


Figure
8

solve a problem. For example, Equation 3 ($P = EI$) can be rearranged to solve for either voltage or current. The rearranged forms of Equation 3 are as follows:

$$E = \frac{P}{I}$$

$$I = \frac{P}{E}$$

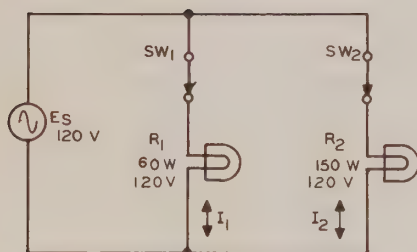


Figure 9

The second of these equations ($I = P/E$) is particularly useful. Many electric devices are designed to operate with a certain source voltage and to use a certain amount of power. For example, light bulbs usually have the voltage and wattage ratings printed on them. When used, these bulbs are connected across the ac line as indicated in Figure 9. The contacts of switches SW_1 and SW_2 must be able to carry the current through them without becoming burned and without arcing.

The contacts of these switches are rated as to the current they can carry and the voltage they can interrupt. In this circuit the source voltage is 120 volts. Bulb R_1 is rated at 60 watts and bulb R_2 is rated at 150 watts.

Using the equation $I = P/E$, we can determine the current each switch must carry. The current through SW_1 is the wattage of R_1 divided by the source voltage: $I_1 = 60/120 = .5$ ampere. The current through SW_2 is $150/120 = 1.25$ amperes. Thus, switch SW_1 must be able to carry .5 ampere and switch SW_2 must be able to carry 1.25 amperes.

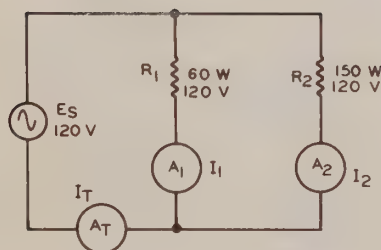


Figure 10

The currents in the circuit of Figure 9 can be measured by the arrangement of Figure 10. Here the bulbs are indicated by resistors R_1 and R_2 . The switches are eliminated and ammeters are connected to measure the total current, the current through R_1 and the current through R_2 .

In many circuits, fuses are employed as safety devices. Basically, a fuse is a low resistance element that is designed to carry a certain amount of current. If that amount of current is exceeded, the element melts and opens the circuit. In this way, the fuse protects the wiring and the source of voltage from being overloaded. As a rule, a fuse is chosen so that the normal load current through it is slightly less than the current rating of the fuse.

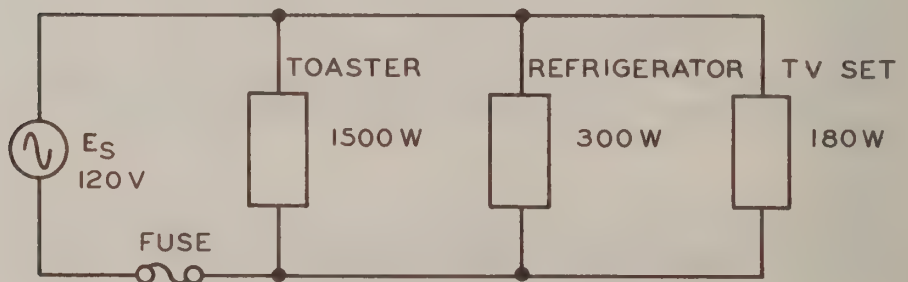
The following Practice Exercise questions cover the subjects which you have just studied. They are:

ENERGY AND POWER

POWER MEASUREMENT AND POWER DISSIPATION

1. What is the unit of electric energy and how is it determined?
2. Where electric power is concerned, both time and electric energy must be considered. True or False?
3. The ampere includes time in its definition. True or False?
4. What is the basic unit of measure of electric power?
5. Knowing the voltage across a resistor and its resistance value, how is the current through it found?
6. Electric power is equal to (a) voltage times current, or EI , (b) current times resistance, or IR , (c) voltage divided by resistance, or E/R .
7. In Figure 1, if you used a 200 volt battery in place of a 100 volt battery, how much electric power would be dissipated by R_1 ?
8. In Figure 3, assume the ammeter reads 3 amperes. How much power is being used by the load?
9. If the supply voltage in Figure 3 is increased to 25.2 volts and the ammeter still reads 3 amperes, how much power is being used by the load?

10. One milliwatt is (a) one-millionth of a watt, (b) one million watts, (c) one-thousandth of a watt, (d) one thousand watts.
11. In Figure 4, change the source voltage from 30 volts to 60 volts. Calculate the power dissipated by each resistor and the total power.
12. How many watts of power are dissipated by a 15 ohm resistor which has 3 amperes of current flowing through it?
13. How many watts are dissipated by an 18 ohm resistor which is connected across a 6 volt source?
14. In the parallel circuit of Figure 10, what is the relationship between the total current in the circuit, I_T , and the currents in each leg of the circuit, I_1 and I_2 ?
15. In the circuit shown below, which of the following fuses should you use? (a) 10 ampere fuse, (b) 15 ampere fuse, (c) 20 ampere fuse, (d) 30 ampere fuse.



POWER RATINGS OF ELECTRIC LOADS

All electric loads are rated as to the amount of power they normally use or dissipate. This rating is not always specified simply in terms of wattage. Ratings may give voltage, or voltage and current, or voltage and wattage.

The power rating of a device, a room air conditioner for example, is usually specified in terms of voltage and current. Also, the unit must be operated under the proper conditions. Let's assume that an air conditioner has a motor which is designed to draw 3 amperes of current when connected across 120 volts and operating normally. The power used by this motor is then 360 watts ($120 \text{ volts} \times 3 \text{ amperes}$).

If the only available voltage source is 240 volts, you cannot connect this motor directly across it. The current would increase and the amount of power used by the motor would be much more than normal. As a result, the motor would burn out in a very short time.

If this same motor were connected across a source voltage much lower than 120 volts, it might not be able to develop enough turning force to move its mechanical load. If a motor does not rotate, it can draw excessive current and exceed its power rating. Thus, we see that it is important to operate an electric motor at its rated voltage if we expect it to deliver the mechanical power intended without damage to the motor.

Other electric loads, such as light bulbs, have both a voltage and wattage rating. Light bulbs for home use are all rated at 120 volts but they may have wattage ratings of 60 watts, 100 watts, 150 watts, etc. These ratings mean that the bulb will dissipate its rated wattage when connected to a source of 120 volts. If the voltage source is less than 120 volts, the bulb dissipates less than its rated wattage and gives off less light. If the voltage source is more than 120 volts, the bulb dissipates more than its rated wattage and will probably burn out sooner.

Other common electric loads are the vacuum tubes used in radios, TV sets, and other types of electronic equipment. Inside a vacuum tube there is a special heating element which heats the tube to its proper operating temperature. Each vacuum tube requires a specific amount of voltage and current. In Figure 11, the heating elements of three tubes (designated R_1 , R_2 and R_3) are connected in series with resistor R_X . Heating elements R_1 and R_2 both

require 35 volts and .15 ampere. Element R_3 requires 12 volts and .15 ampere. By connecting the three elements as a series circuit, the total voltage required is the sum of the individual voltages, or 82 volts.

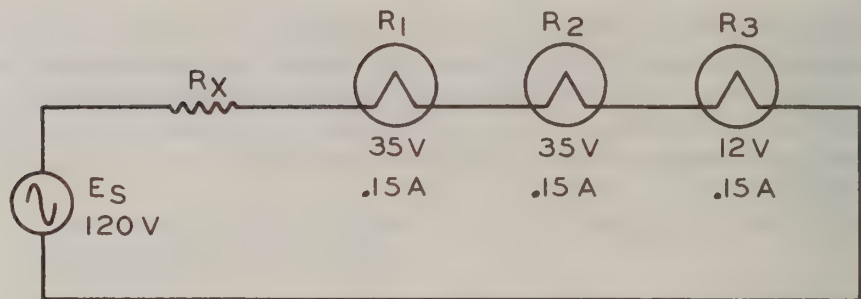


Figure 11

By connecting this series arrangement of heating elements directly across the 120 volt source in your home without R_X , the power rating of each element would be exceeded, and the elements would probably burn out. To prevent this undesirable condition from happening, resistor R_X is connected in series with the heating elements shown in Figure 11. Since the voltage required for the three heating elements is 82 volts, the voltage across R_X must be $120 - 82$, or 38 volts.

The current through R_X is the same as through the other components (.15 ampere). The required resistance of R_X is found by Ohm's Law as follows:

$$R_X = \frac{E_R}{I} = \frac{38}{.15} = 253 \frac{1}{3} \text{ ohms.}$$

In actual practice, a 250 ohm resistor (a standard value) would be used for R_X so the tube heating elements would dissipate the proper amount of power.

Resistor R_X cannot be just any 250 ohm resistor. Since it has 38 volts across it and .15 ampere through it, the power dissipated by R_X is:

$$P = EI = 38 \times .15 = 5.7 \text{ watts.}$$

Therefore, R_x must be capable of dissipating at least 5.7 watts without overheating. In most cases, it is a good policy to use a resistor which has a higher wattage rating than the amount of wattage the resistor is actually dissipating. In this case an 8 watt resistor will provide a margin of safety. Remember that any wattage rating greater than 5.7 watts is satisfactory for R_x in this case. However, the greater the wattage rating of a resistor, the larger and more expensive it becomes.



The power consumption of a piece of electronic equipment is generally given along with other specifications. The input power consumption of this mixer amplifier is 10 watts.

Courtesy R. T. Bozak Mfg. Co.

Also remember that the power ratings of electric loads are very important. For devices such as lamps, toasters, TV sets, and radios, the power used or dissipated by each unit should be very close to the wattage rating of the unit. Otherwise, the unit will not operate properly and, in some cases, may be damaged. Where resistors are concerned, the wattage rating specifies the maximum amount of power that may be safely dissipated by the resistors. A 10 watt resistor should not be used in a circuit where the resistor will have to dissipate 11 watts of power. However, a 10 watt resistor may be used in a circuit where the resistor dissipates any amount of power less than 10 watts. In actual practice, the power dissipated by a resistor should not be much more than half of its power rating. This is to prevent overheating.

POWER RATINGS OF ELECTRIC SOURCES

There are many sources of electric power. The most common of these sources (which supply electric power to homes, factories and businesses) are the

electric power generating stations. Let's consider a generating station capable of producing 180,000 kilowatts. (The prefix "kilo" means 1000; therefore, a **KILOWATT** is 1000 watts. Thus, 180,000 kilowatts is the same as 180,000,000 watts.) The voltage produced by this particular power station is 14,400 volts. This power station is capable of supplying 12,500 amperes. Multiplying the voltage by the current gives the power capability of 180,000 kilowatts.

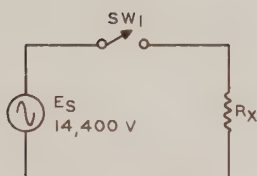


Figure
12

Remember that all sources of electric power are limited as to the amount of electric power they can produce. Even this power station has the 180,000 kilowatt limit which must not be exceeded. Figure 12 is a simplified schematic diagram where E_s represents the power station and resistor R_x represents the load. In this case, the load might be all of the homes and industries in a small town. This load might also change considerably. With SW_1 closed, and assuming R_x is 10 ohms, the current through R_x is:

$$I = \frac{E_s}{R_x} = \frac{14,400}{10} = 1440 \text{ amperes.}$$

Since the power station is capable of supplying 12,500 amperes, it can supply 1440 amperes very easily. The total power supplied is:

$$P = EI = 14,400 \times 1440 = 20,736,000 = 20,736 \text{ kilowatts,}$$

which is considerably less than the 180,000 kilowatts the station is capable of supplying.

However, if the homes and industries suddenly started using more electricity, the resistance of R_x would effectively be reduced. Let's assume that R_x reduces to 1 ohm. Now the current is:

$$I = \frac{E_s}{R_x} = \frac{14,400}{1} = 14,400 \text{ amperes,}$$

and the power is:

$$P = EI = 14,400 \times 14,400 = 207,360 \text{ kilowatts.}$$

In this case, the total current and total power demanded by the load are greater than the station is capable of supplying. As a result, the equipment in the power station is overworked and would be damaged if precautions were not taken. To prevent damage to the equipment, power stations have special switching arrangements which automatically remove excessive loads.

The power rating of any source specifies the **MAXIMUM** amount of power the source can safely supply to a load. For example, a source that is rated at 1000 watts should not be used to supply more than 1000 watts of power or it may be damaged.

Internal Resistance of the Source

There are several reasons why a source of electric energy has limited power capabilities. One reason is that all sources of electric power have **INTERNAL RESISTANCE**. This is shown in Figure 13 by dividing the battery into two parts and inserting its internal resistance, R_I , between the two parts. Resistance R_I is not a resistor which is connected into the circuit; it is an internal part of the battery.

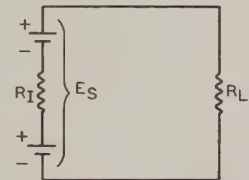


Figure 13

Often, the internal resistance of a source is not shown on a schematic diagram. However, when it is shown it is usually drawn in series with the source as shown in Figure 14. Since all current delivered by the source flows through this resistance, Figure 14 is basically the same as Figure 13. Figure 14 is easier to draw and use.

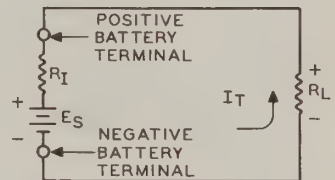


Figure 14

Referring to Figure 14, let's assign some values to the various components. Assume E_S is 100 volts, R_L is 99 ohms and R_I is 1 ohm. The total resistance in the circuit is the sum of R_L and R_I , or 100 ohms. The total current, I_T , is:

$$I_T = \frac{E_S}{R_T} = \frac{100}{100} = 1 \text{ ampere.}$$

The voltage across R_L is:

$$E_{R_L} = I_T R_L = 1 \times 99 = 99 \text{ volts.}$$

The voltage across R_I is:

$$E_{R_I} = I_T R_I = 1 \times 1 = 1 \text{ volt.}$$

The 1 volt across R_I cannot be measured with a voltmeter since it occurs inside the battery. Its net effect is that the voltage actually available at the battery terminals is 99 volts instead of 100 volts. This reduced E_S appears across load resistance R_L .

A loss of 1 volt out of 100 volts is not too serious and can be tolerated. Suppose R_L is changed from 99 ohms to 9 ohms. The total resistance is now 10 ohms and the total current becomes 10 amperes. With 10 amperes of current in the circuit, the voltage across the internal resistance, R_I , is 10 volts, which leaves only 90 volts at the battery terminals. Under these conditions, the power used by the load resistance, R_L , is 900 watts (90 volts $\times$ 10 amperes) while the power dissipated by the internal resistance, R_I , is 100 watts (10 volts $\times$ 10 amperes).

Since the power dissipated by the internal resistance of the source is wasted, it is desirable that the internal resistance be as small as possible. The ideal situation would be an internal resistance of zero. Unfortunately, this is not possible, and all power sources have some internal resistance.

Resistance of Connecting Wires

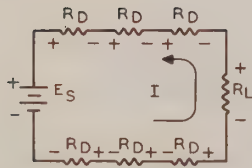


Figure 15

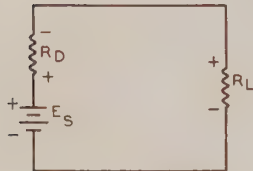


Figure 16

Another cause of power losses is the resistance of the wires that connect the source to the load. This resistance is distributed evenly along the entire length of the wires as shown in Figure 15. Here the circuit current flows through the distributed resistance, shown as six resistors labeled R_D , as well as through the load resistance, R_L . The voltage across the distributed resistance is wasted, since this voltage does not appear across the load resistance.

Rather than show the distributed resistance as many resistors on a schematic diagram, it is common practice to show the entire resistance of the connecting wires as one resistor. Thus, in Figure 16 the single resistor R_D represents the resistance of the wires that connect the source to the load.

The effects of distributed resistance are best illustrated by examples. In your home, an electric toaster may require 1800 watts of electricity at 120 volts for proper operation. We can determine the current drawn by the toaster as follows:

$$I = \frac{P}{E} = \frac{1800}{120} = 15 \text{ amperes.}$$

Using Ohm's Law and solving for the resistance of the toaster:

$$R = \frac{E}{I} = \frac{120}{15} = 8 \text{ ohms.}$$

Now we have all of the necessary information about the toaster. It operates on 120 volts, has 8 ohms of resistance, draws 15 amperes of current, and dissipates 1800 watts of power. We still need information concerning the

line cord used to connect the toaster to the source of electricity. Let's assume the line cord is 8 feet long and is made with No. 18 gauge stranded wire. The resistance of No. 18 gauge wire is about .006 ohm per foot. Since an 8 foot line cord has 16 feet of wire, the total resistance of the line cord is about .1 ohm. With 15 amperes of current through the line cord, the voltage lost is:

$$E = IR = 15 \times .1 = 1.5 \text{ volts.}$$

The power dissipated in the line cord is:

$$P = EI = 1.5 \times 15 = 22.5 \text{ watts.}$$

In this case, the 22.5 watts of power dissipated in the line is wasted as it does nothing except heat up the line cord. Although 22.5 watts of power distributed over an 8 foot line cord is undesirable, no real damage would occur and the toaster would operate normally.

However, assume that most of the strands in the cord have become broken through use and the resistance of the cord increases to 1 ohm. The circuit would now be as shown in Figure 17. The total resistance is:

$$R_T = R_D + R_L = 1 + 8 = 9 \text{ ohms.}$$

The circuit current now becomes:

$$I = \frac{E}{R} = \frac{120}{9} = 13.3 \text{ amperes.}$$

The voltages across R_D and R_L are as follows:

$$E_{R_D} = IR_D = 13.3 \times 1 = 13.3 \text{ volts}$$

$$E_{R_L} = IR_L = 13.3 \times 8 = 106 \text{ volts.}$$

The power dissipated by R_D is:

$$P_{R_D} = E_{R_D}I = 13.3 \times 13.3 = 177 \text{ watts (approx.).}$$

The power dissipated by R_L is:

$$P_{R_L} = E_{R_L}I = 106 \times 13.3 = 1410 \text{ watts (approx.).}$$

The power used in the toaster is now only 1410 watts, instead of the normal 1800 watts, so the toaster may not function properly. In addition, the power wasted in the line cord resistance is 177 watts, which is far greater than the average line cord can withstand, so the cord will overheat and may burn up.

Remember, it is very important that the resistance of connecting wires between the source and the load, and the internal resistance of the source, be kept as low as possible. Both of these resistances limit the amount of power that can be supplied by a source or used by a load.

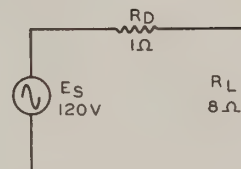


Figure
17

SUMMARY

The power rating of a source of electric energy—battery, power station, etc.—tells you the maximum amount of power that the source can supply. The power rating of a resistor tells the maximum amount of power that the resistor can safely dissipate. The power rating of a load tells you that the load should dissipate a specific amount of power. If the load dissipates more power, it will probably be damaged. If it dissipates less power, it will not function properly.

The total power being used in any electric circuit may be determined in various ways. The source voltage can be multiplied by the total current ($P = EI$); the square of the source voltage can be divided by the circuit resistance ($P = E^2/R$); the circuit current can be squared and multiplied by the circuit resistance ($P = I^2R$); or the power dissipated by each of the components may be calculated and added together to obtain the total power dissipated ($P_T = P_1 + P_2 + P_3 \dots$ etc.).

The following Practice Exercise questions cover the subjects which you have just studied. They are:

POWER RATINGS OF ELECTRIC LOADS

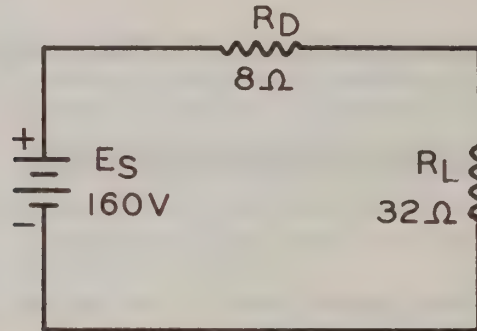
POWER RATINGS OF ELECTRIC SOURCES

INTERNAL RESISTANCE OF THE SOURCE

RESISTANCE OF CONNECTING WIRES

16. A particular electric motor is rated at 120 volts and 5 amperes. Why is it not simply rated at 600 watts?
17. In the circuit of Figure 11, if E_s were 100 volts instead of 120 volts, what value of resistance would you use for R_x ? How much power would you expect R_x to dissipate?
18. Referring to Exercise 17, if the available resistors have wattage ratings of 1W, 2W, 5W and 10W, which wattage rating would you use?
19. All 12 volt sources are capable of supplying the same amount of electric power. True or False?
20. In Figures 13 and 14, what does R_i represent?
21. In the circuit of Figure 14, minimum loss is obtained when (a) R_L is as small as possible, (b) R_i is equal to R_L , (c) R_i is as small as possible.

22. In the circuit of Figure 15, the resistors labeled R_D (a) are voltage dropping resistors to prevent overloading R_L , (b) represent the resistance of the wires that connect the source to the load, (c) are unimportant and have no effect on any circuits.
23. In the circuit below, how much power is used in R_L ? How much power is lost in R_D ?



IMPORTANT DEFINITIONS

ELECTRIC POWER — The rate of producing or using electric energy.

INTERNAL RESISTANCE — The resistance which is part of an electric device because of its physical construction.

JOULE (J) — The basic unit of energy measurement equal to a volt coulomb.

KILOWATT (kW) — One thousand watts.

MICROWATT (μ W) — One-millionth of a watt.

MILLIWATT (mW) — One-thousandth of a watt.

WATT (W) — The basic unit of measure of electric power. One watt is equal to one ampere of current at a potential of one volt.

ESSENTIAL SYMBOLS AND EQUATIONS

E_n energy (joules)

E voltage (volts)

I current (amperes)

P power (watts)

Q coulombs (6.28×10^{18} electrons)

T time (seconds)

$$E_n = EQ \quad (1)$$

$$P = \frac{E_n}{T} = \frac{EQ}{T} \quad (2)$$

$$P = EI \quad (3)$$

$$P_T = P_1 + P_2 + \dots \text{etc.} \quad (4)$$

$$P = I^2R \quad (5)$$

$$P = \frac{E^2}{R} \quad (6)$$

PRACTICE EXERCISE SOLUTIONS

1. The joule is the unit of electric energy and it is equal to a volt coulomb.
2. True — By definition, electric power is the rate of using or producing electric energy.
3. True — An ampere is defined as one coulomb of electrons passing a given point in one second.
4. The watt.
5. The current is found by dividing the voltage across the resistor by its resistance value. This is a form of Ohm's Law and can be written:
 $I = E/R$.
6. (a) voltage times current, or EI .
7. 800 watts. — With E_s equal to 200 volts, the current is $200 \div 50$ or 4 amperes. The power dissipated is 200×4 , or 800 watts.
8. 37.8 watts. — $P = EI = 12.6 \times 3 = 37.8$ watts.
9. 75.6 watts. — $P = EI = 25.2 \times 3 = 75.6$ watts.
10. (c) one-thousandth of a watt.
11. Power dissipated by $R_1 = .4$ watt, power dissipated by $R_2 = .8$ watt, total power dissipated = 1.2 watts. — The problem is solved as follows:

Total resistance	= $1000 + 2000 = 3000$ ohms
Total current	= $60/3000 = .02$ ampere
Voltage across R_1	= $.02 \times 1000 = 20$ volts
Voltage across R_2	= $.02 \times 2000 = 40$ volts
Power dissipated by R_1	= $20 \times .02 = .4$ watt
Power dissipated by R_2	= $40 \times .02 = .8$ watt
Total power	= $60 \times .02 = 1.2$ watts.
12. 135 watts. — $P = I^2R = 3^2 \times 15 = 9 \times 15 = 135$ watts.
13. 2 watts. — $P = \frac{E^2}{R} = \frac{6^2}{18} = \frac{36}{18} = 2$ watts.
14. $I_T = I_1 + I_2$. — In a parallel circuit, the total current is equal to the sum of the branch currents.
15. (c) 20 ampere fuse. — When the wattage and voltage are known, current is determined by $I = P/E$. Thus, the toaster current is 12.5 amperes, the refrigerator current is 2.5 amperes, the TV set current is 1.5 amperes and the total current is the sum of these currents, which is 16.5 amperes. Since the fuse must carry the total current, the 20 ampere fuse is the smallest of the choices which is rated at more than 16.5 amperes.

PRACTICE EXERCISE SOLUTIONS (Continued)

16. A 120 volt, 5 ampere electric motor is not rated at 600 watts because operation at the proper voltage is important. In addition, motors are not usually compared according to wattage used, but more often by the mechanical horsepower they can produce.
17. 120 ohms; 2.7 watts. — The voltage across R_X would be $100 - 82$, or 18 volts. The resistance of R_X would have to be:

$$R_X = \frac{E_{R_X}}{I_T} = \frac{18}{.15} = 120 \text{ ohms.}$$

The power dissipated by R_X would be:

$$P_{R_X} = E_{R_X} I_T = 18 \times .15 = 2.7 \text{ watts.}$$

18. 5W. — The resistor must have a wattage rating equal to, or greater than, the amount of power it dissipates. The 10 watt resistor could be used as well as the 5 watt resistor. However, a 5 watt resistor provides a sufficient safety factor for most applications, and at a lower cost.
19. False — The voltage produced by a battery is not the only factor which determines its power capabilities. The power it can supply is determined by both its voltage and its current capabilities.
20. The internal resistance of the source.
21. (c) R_I is as small as possible.
22. (b) represent the resistance of the wires that connect the source to the load.
23. $P_{R_L} = 512$ watts, $P_{R_D} = 128$ watts. — The problem is solved as follows:

$$R_T = R_D + R_L = 8 + 32 = 40 \text{ ohms}$$

$$I_T = \frac{E_S}{R_T} = \frac{160}{40} = 4 \text{ amperes}$$

$$E_{R_D} = I_T R_D = 4 \times 8 = 32 \text{ volts}$$

$$E_{R_L} = I_T R_L = 4 \times 32 = 128 \text{ volts}$$

$$P_{R_D} = E_{R_D} I_T = 32 \times 4 = 128 \text{ watts}$$

$$P_{R_L} = E_{R_L} I_T = 128 \times 4 = 512 \text{ watts.}$$

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE
1013A

Example:

A	☐
B	☒
C	☐
D	☐

Neptune is the name of a

A. cigarette. B. planet. C. plant. D. Chinese holiday.

1. A ☐ B ☐ C ☐ D ☐ In an electric circuit where the source voltage is 200 volts and the total circuit current is 2 amperes, how much power is being used?
(A) 100 watts. (B) 400 watts. (C) 600 watts. (D) 202 watts.
2. A ☐ B ☐ C ☐ D ☐ Of the following sources, which can provide the most power?
(A) A 60 volt source capable of supplying 10 amperes. (B) A 100 volt source capable of supplying 10 amperes. (C) A 12 volt source capable of supplying 10 amperes. (D) A 30 volt source capable of supplying 10 amperes.
3. A ☐ B ☐ C ☐ D ☐ The basic unit of measure of electric power is the
(A) ampere. (B) watt. (C) volt. (D) ohm.
4. A ☐ B ☐ C ☐ D ☐ When a resistor has a 10 watt rating, this means that it
(A) always dissipates exactly 10 watts of power. (B) always provides 10 watts of power. (C) should be used in a circuit where it will dissipate more than 10 watts of power. (D) can safely dissipate 10 watts, or less, of power.
5. A ☐ B ☐ C ☐ D ☐ An energy source with a 10 watt power rating can safely be used to supply
(A) a 100 watt load. (B) a 1000 watt load. (C) a 5 watt load. (D) a 20 watt load.
6. A ☐ B ☐ C ☐ D ☐ A resistor is connected to a 100 volt dc source. How much power is dissipated by the resistor if the circuit current is 5000 mA?
(A) 20 watts. (B) 500 watts. (C) 25 watts. (D) 100 watts.
7. A ☐ B ☐ C ☐ D ☐ A 5 ohm resistor is connected to a 20 volt ac source. How much power is dissipated by the resistor?
(A) 100 watts. (B) 4 watts. (C) 5 watts. (D) 80 watts.
8. A ☐ B ☐ C ☐ D ☐ In any circuit consisting of three resistors, the total power being dissipated is
(A) less than the power being dissipated by any one resistor. (B) equal to the sum of the powers dissipated in all three resistors. (C) divided equally among the resistors. (D) determined by multiplying the source voltage by the current through one of the resistors.
9. A ☐ B ☐ C ☐ D ☐ Electric power is the
(A) same as electric pressure. (B) total number of electrons forced through a circuit. (C) number of electrons passing a given point in one second. (D) rate of using or producing electric energy.
10. A ☐ B ☐ C ☐ D ☐ How much current is drawn by a circuit which dissipates 4800 watts of power when the source voltage is 120 volts?
(A) 20 amperes. (B) 40 amperes. (C) 400 amperes. (D) 200 amperes.

USING ELECTRIC METERS

1016

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This electronic milliammeter employs a special clip-on probe that permits current measurements without opening the circuit. The probe is clipped around the wire carrying the current to be measured.

Courtesy Hewlett-Packard Co.

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When someone doing a piece of work says "Let it go, that's good enough," it is generally a pretty good sign that it was not good enough. If it were, no one would need convincing.

—Dr. Frank Crane

USING ELECTRIC METERS

To put electricity to work, we must control electrons. Electrons are invisible to the human eye. We can only detect their presence by observing the effects they produce. For example, we detect the presence of electron flow in a light bulb by observing the heat and light generated by the bulb.

Meters are the “eyes” that permit us to observe the invisible action in a circuit. They are indispensable when we are examining the operation of a circuit or troubleshooting a piece of equipment.

Meters can indicate voltage, current, resistance and many other quantities. To use these meters, we must connect them properly to the circuit under test. We must also read the scales properly. Improper meter connections can give false measurements and, in some instances, damage the meters. It is important to learn the proper (and quite simple) methods of connecting meters and of reading their scales.

METERS

There are two general types of meters. One type consists of an electro-mechanical mechanism which moves a pointer across a scale. This type of meter is called an **ELECTRIC METER**. The other type consists of a transistor or vacuum tube circuit working together with an electric meter. This combination is referred to as an **ELECTRONIC METER**. The methods of using and reading both types of meters are basically the same.

Figure 1A shows a typical electric meter. The amount of pointer movement, called pointer **DEFLECTION**, depends on the current through or voltage applied to the meter. The meter is connected to a circuit by using the terminals at the back of the meter shown in Figure 1B.

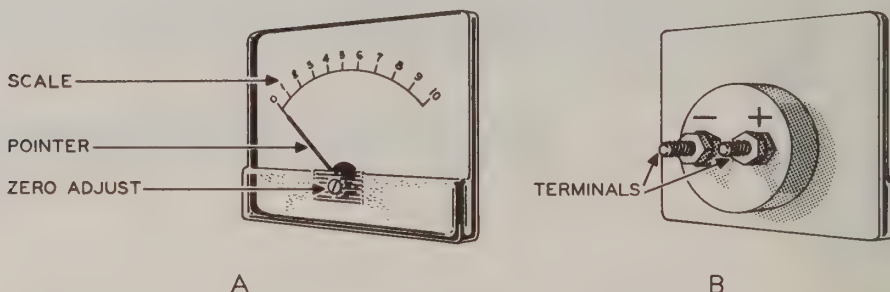


Figure 1

To protect the meter as well as to provide an easy means of connecting and carrying the meter, it is often housed in a case, as shown in Figure 2. The meter terminals of Figure 1B are permanently connected to the jacks on the case shown in Figure 2. You connect test leads to the jacks whenever you use the meter. Polarity markings (+ and -) indicate how to connect the meter. Often a red jack is used to indicate positive and a black jack is used to indicate negative.

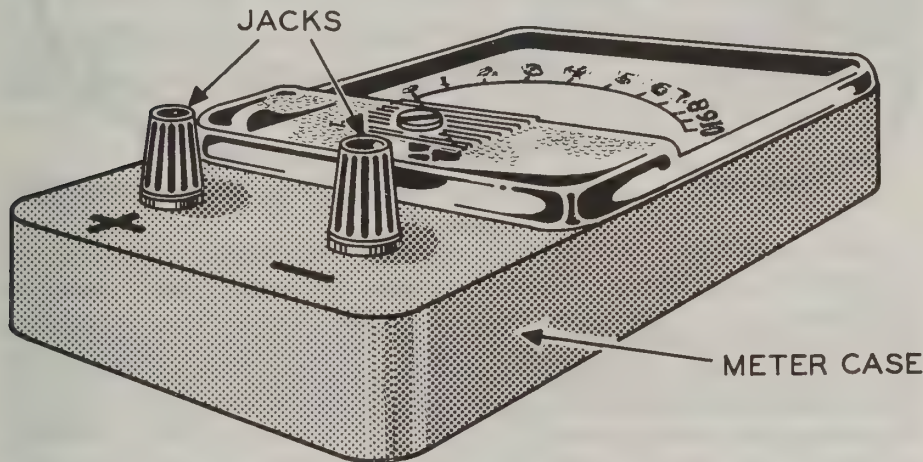


Figure 2

Most meters contain a mechanical zero adjustment. The small screw shown on the meter in Figure 1A provides this adjustment. To zero adjust the meter, a small screwdriver is inserted into the slot and the screw is turned one way or the other until the pointer is exactly over the zero mark on the scale (as shown by pointer position A in Figure 3). Positions B and C in Figure 3 show the position of the pointer when the meter is not correctly zero adjusted. The meter should not be connected to any circuit during the zero adjustment.

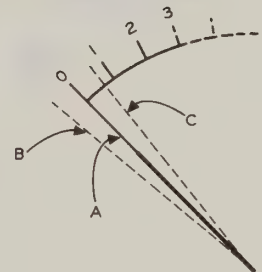


Figure
3

HOW TO MEASURE CURRENT

To measure the dc current in a circuit, you connect a dc current meter in SERIES with the circuit. Figure 4 shows a pictorial diagram of how to connect an ammeter to measure current from a dry cell through two resistors. An **AMMETER** is an instrument calibrated to measure current in amperes. (Note: The ammeter is connected so that electrons flow into its negative terminal and out of its positive terminal.) The meter pointer deflects to a point on the scale that corresponds to the amount of circuit current. If you reversed the meter leads, the pointer would deflect to the left, off scale, and the delicate meter mechanism might be damaged.

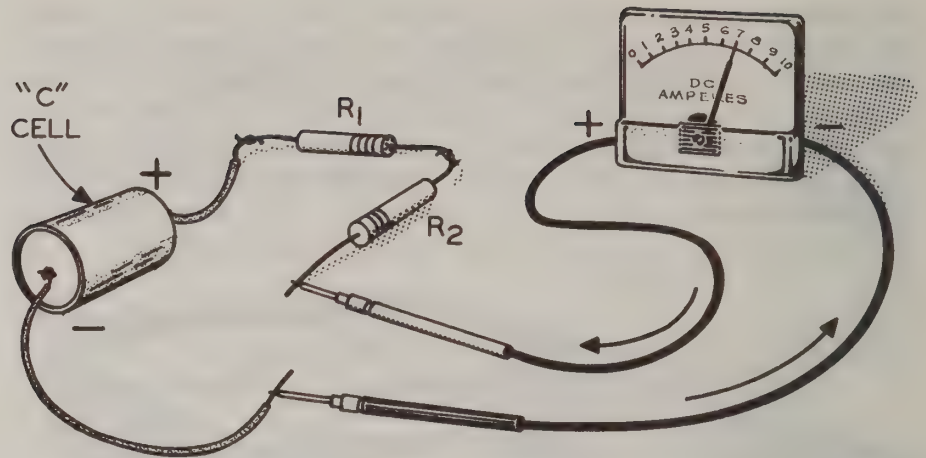


Figure 4

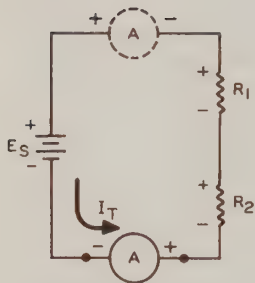


Figure 5

Figure 5 shows a schematic diagram of the circuit shown in Figure 4. A circle with the letter A inside represents the ammeter. Note that the meter is connected so that the circuit current flows through the meter from — to +. To measure the circuit current in Figure 5, the meter can be connected anywhere in the circuit since the current is the same at all points in a series circuit. For example, the ammeter could be connected in the position shown by the broken circle. In this position the ammeter would measure the same current that was measured by the ammeter represented by the solid circle.

Figure 6A shows how to connect an ammeter into a parallel circuit to measure the total current, I_T . Remember, the meter is to be connected so that total circuit current flows through the meter from — to +. The total circuit current could also be measured by connecting the ammeter in the position shown by the broken circle. If the meter were connected in series with R_1 or R_2 , it would only measure the current through R_1 or R_2 and not the total circuit current.

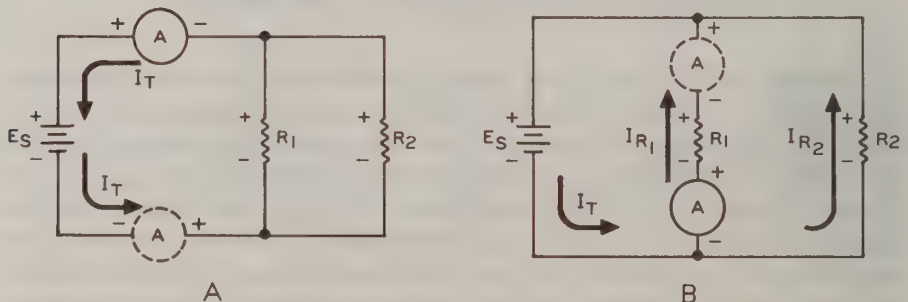


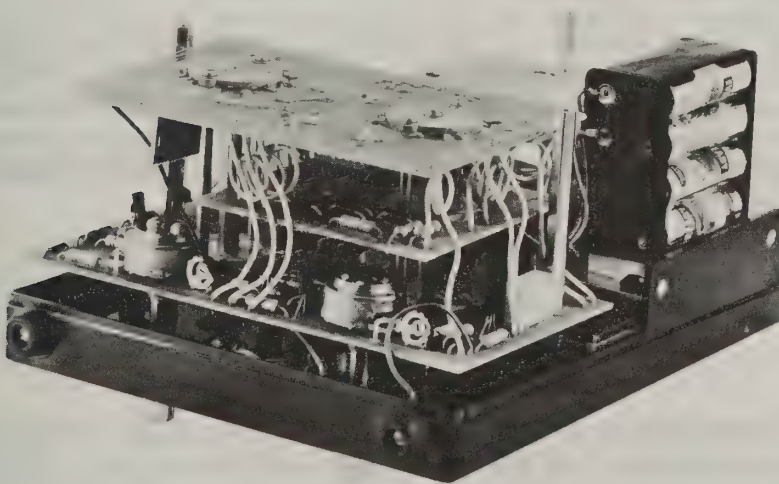
Figure 6

Figure 6B shows how to connect an ammeter to measure the current through resistor R_1 (I_{R_1}). The meter might also be connected in the position shown by the broken circle. In either case, only the current through R_1 flows through the meter. To measure the current in resistor R_2 (I_{R_2}), connect the meter in series with R_2 .

A CURRENT METER MUST BE CONNECTED IN SERIES WITH A CIRCUIT SO THAT THE CURRENT TO BE MEASURED FLOWS THROUGH THE METER.

Milliammeters and Microammeters

Remember, an ammeter is an instrument calibrated to measure current in amperes. In many electric and electronic circuits, currents in the milliamperere (.001A) or microampere (.000001A) range are found. If an ammeter is used to measure these currents, the pointer may barely deflect from the zero mark. To measure small currents, a more sensitive current meter, one that is capable of measuring smaller currents, is used.



This photo shows the internal construction of an electronic meter. Meters of this type employ transistor amplifiers to increase the sensitivity of the meter movement.

Courtesy Delta Products Inc.

A **MILLIAMMETER** is a meter calibrated to measure current in milliamperes. A milliammeter is therefore more sensitive than an ammeter. A **MICROAMMETER** is calibrated to measure current in microamperes. A microammeter is more sensitive than either a milliammeter or ammeter.

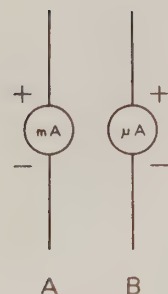


Figure 7

Special symbols are used for the milliammeter and microammeter, as shown in Figure 7. Figure 7A shows the symbol for a milliammeter and Figure 7B shows the symbol for a microammeter.

Loading Effects

A current meter (ammeter, milliammeter or microammeter) must be inserted in series with a circuit to measure current. A perfect or "ideal" current meter would have zero internal resistance. If this "ideal" meter were inserted into a circuit, it would not alter the resistance of the circuit.

However, practical current meters do have some internal resistance. The internal meter resistance increases the resistance of the circuit when the meter is inserted. The measured circuit current is therefore lower than the actual circuit current before the meter is inserted. However, in most cases the resistance of a current meter is very small as compared to the circuit resistance, and therefore the error can be ignored.

Special types of ammeters are also available. One of these uses a clip-on technique for measuring current. Arms on this type of meter encircle a current-carrying conductor. The strength of the magnetic field surrounding the current-carrying conductor is sensed. The more current in the conductor, the stronger the magnetic field around it. The meter scale is calibrated in terms of current.

HOW TO MEASURE VOLTAGE

A dc **VOLTMETER** is designed to measure the dc voltage, or difference of potential, between two points. Voltage exists between two points and does not flow through a circuit like current. As a result, a voltmeter is not connected in series like an ammeter. Instead, a voltmeter is connected across or in PARALLEL with the points across which the voltage appears.

Figure 8 shows how a voltmeter is connected to measure the voltage across a resistor. The polarity of a dc voltmeter must also be observed. The negative terminal of the voltmeter is connected to the more negative point. If the connections are reversed, the meter pointer deflects to the left, off scale, and damage to the voltmeter may result.

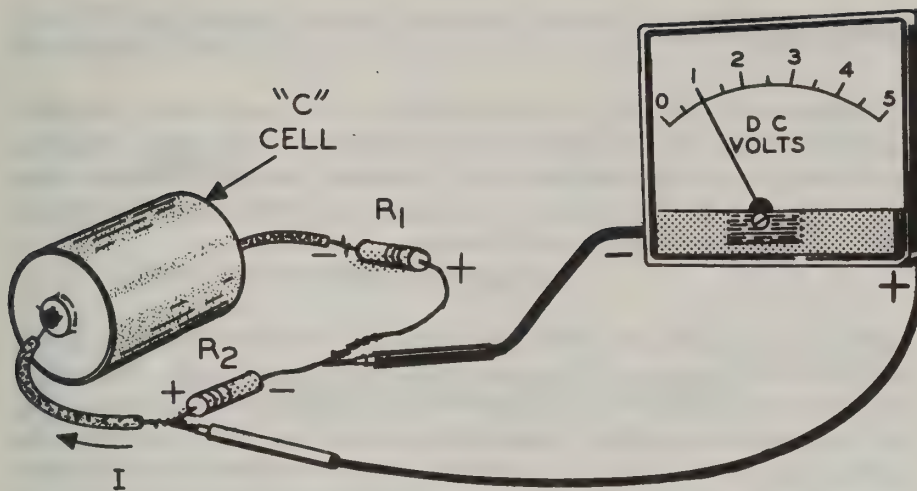


Figure 8

Figure 9A shows a schematic diagram of the pictorial drawing shown in Figure 8. The voltmeter is represented by the circle with the letter V inside. Note the polarity of the voltmeter and the fact that it is connected **IN PARALLEL OR ACROSS THE CIRCUIT** and not in series with the circuit. To measure the voltage across R_1 , the voltmeter is connected in parallel with R_1 , as shown in Figure 9B.

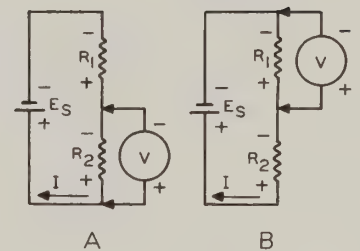


Figure 9

Kilovoltmeters, Millivoltmeters and Microvoltmeters

High voltages, on the order of several thousand volts, are often found in electric or electronic circuits. Special voltmeters are often used to measure these high voltages. The meters are calibrated to indicate voltage in kilovolts (1000 volts) and are called **KILOVOLTMETERS**.

Very small voltages are also encountered in electric or electronic circuits, especially in transistor circuits. Sensitive voltmeters are then used to measure these low voltages. In many cases these special voltmeters are electronic voltmeters. Some sensitive voltmeters are calibrated to indicate voltage in millivolts (.001 volt) and are called **MILLIVOLTMETERS**. Other sensitive voltmeters are calibrated to indicate voltage in microvolts (.000001 volt) and are called **MICROVOLTMETERS**.

The special symbols that are used for kilovoltmeters, millivoltmeters and microvoltmeters are shown in Figure 10. Figure 10A shows the symbol used for a kilovoltmeter; Figure 10B shows the symbol for a millivoltmeter; and Figure 10C shows the symbol for a microvoltmeter.

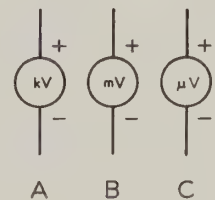


Figure 10

Loading Effects

A voltmeter will also affect the circuit under test to some extent. An ideal voltmeter would have an infinite internal resistance and, when connected to a circuit, would have no effect on it. However, practical voltmeters have a resistance of less than infinity. The higher the internal resistance of the voltmeter, the more accurate the reading.

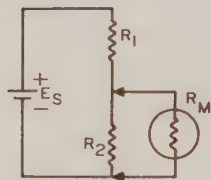


Figure
11

Figure 11 shows how the internal resistance of a voltmeter affects the circuit under test. R_M represents the internal resistance of the voltmeter. Remember that the meter resistance is in parallel with the resistor to be measured. The total resistance of a parallel circuit is always less than the resistance of the smallest individual resistance. Therefore, with the resistance of the meter connected across R_2 , the effective resistance of R_2 is decreased. Ohm's Law, $E = IR$, shows that when resistance decreases, voltage decreases. As a result, the voltmeter indicates a voltage smaller than the actual voltage across R_2 .

In most cases the internal resistance of a voltmeter is much higher than the circuit resistance. The error is therefore small and can be neglected. However, when making voltage measurements in high-resistance circuits, the meter resistance will have a noticeable effect. Electronic voltmeters have very high internal resistance to minimize the loading effect.

READING AMMETERS AND VOLTMETERS



Figure
12

In general, you read both ammeter and voltmeter scales similarly: when using an ammeter, the readings are in amperes; when using a voltmeter, the readings are in volts. Figure 12 shows the scale of a typical ammeter. This scale reads from 0 to 10 amperes. The maximum value indicated on the scale, in this case 10 amperes, is called the **FULL SCALE** value. The maximum voltage or current a meter can read is equal to its full scale value.

To determine the value of current or voltage, you read the value on the scale under the pointer. For example, assume the pointer shown in Figure 12 deflects to position A. In this position the pointer is over the 1 mark and a current of 1 ampere is indicated. At position C the pointer is over the 9 mark and a current of 9 amperes is indicated. The large numbered marks on a scale are often called the major scale divisions.

If the pointer deflects to a point between major scale divisions, you must use the smaller scale divisions. On the meter face shown in Figure 12,

The following Practice Exercise questions cover the subjects which you have just studied. They are:

METERS

HOW TO MEASURE CURRENT

MILLIAMMETERS AND MICROAMMETERS

LOADING EFFECTS

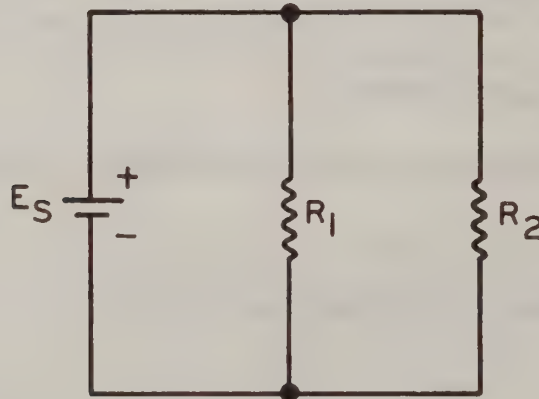
HOW TO MEASURE VOLTAGE

**KILOVOLTMETERS, MILLIVOLTMETERS AND
MICROVOLTMETERS**

LOADING EFFECTS

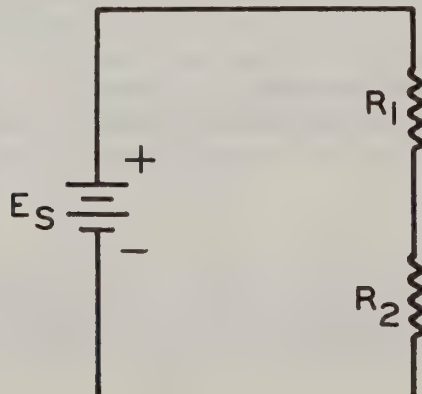
1. How should you zero adjust an electric meter?
2. To measure circuit current, an ammeter must be connected (a) in series with a circuit, (b) in parallel with a circuit.
3. What would happen if you connected an ammeter so that electrons flowed into the + terminal and out of the — terminal?

4. If you have an ammeter with red and black terminals, which terminal is probably positive and which is probably negative?
5. If you connect an ammeter into a circuit that has a resistance of 20 ohms and operates from a 60-volt supply, how much current would you measure?
6. Draw ammeters in the circuit shown below so they will measure total circuit current and the current through R_2 . Be sure to indicate the polarity of connection for each of the meters.



7. How does the sensitivity of ammeters, milliammeters and microammeters compare?

8. Draw the symbol for an ammeter, milliammeter and microammeter.
9. Assume you have two milliammeters with equal current ranges, one with an internal resistance of 50 ohms and the other with an internal resistance of 100 ohms. Which one would have the least effect on the circuit you are testing?
10. A voltmeter must be connected in parallel with a circuit to measure its voltage. True or False?
11. Must you observe the polarity of a dc voltmeter when connecting it?
12. Show how you would connect voltmeters to measure the voltages across R_1 and R_2 in the circuit below. Be sure to indicate voltmeter polarities.



13. If you were to measure a high voltage which is on the order of several thousand volts, what type of voltmeter would you use?

14. Draw the symbols for a voltmeter, kilovoltmeter and microvoltmeter.

15. What would your requirements be regarding voltmeter resistance if you were making voltage measurements in high-resistance circuits?

there are four small scale divisions between major scale divisions. This divides the space between major scale divisions into five equal spaces. The value of a smaller scale division is equal to the value of a larger scale division divided by the number of spaces formed by the small scale divisions. Thus, each small scale division on the meter face shown in Figure 12 has a value of $1 \text{ ampere} \div 5 \text{ spaces}$, which equals .2 ampere.

The first small scale division to the right of zero in Figure 12 has a value of .2 ampere. The second small scale division has a value of .4 ampere (.2 ampere + .2 ampere = .4 ampere). The first small scale division to the right of the 1 mark has a value of 1 plus .2, or 1.2 amperes. The second small scale division to the right of 1 has a value of 1 plus .4, or 1.4 amperes, and so on. Thus, if the pointer is at position B in Figure 12, it would indicate a current of 1.8 amperes.

In some cases the pointer may stop between small scale divisions. For example, assume the pointer is at position A in Figure 13. When this happens, you must estimate the value of current. Here the pointer is about halfway between the 1.2- and 1.4-ampere marks. The current is therefore about 1.3 amperes. As another example, assume the pointer is at position B in Figure 13. In this position the pointer is about 1/4 of the way between the 1.6 and 1.8 marks. Each small mark represents .2 ampere, and 1/4 of .2 ampere is .05 ampere. Thus, the pointer at position B represents a current of about 1.6 plus .05, or 1.65 amperes.

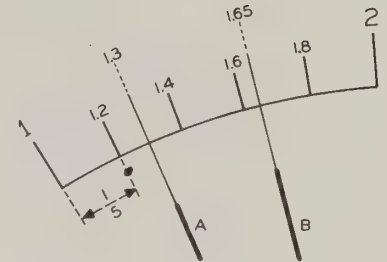


Figure 13

The number of major and smaller scale divisions on a meter scale depends upon the range of voltage or current the meter is designed to measure. In all cases you find the value of the small scale divisions by dividing the value of a major scale division by the number of spaces between the major scale divisions. If the pointer falls between the smaller scale divisions, you must estimate the voltage or current.

Figure 14 shows a dc voltmeter scale. This scale has a full scale value of 150 volts. Note that there is only one small scale division between major scale divisions. This divides the space between major divisions into two spaces. Thus, each small scale division has a value of 1/2 of a major scale division, or 5 volts. If the pointer is at position A in Figure 14, it indicates a voltage of 30 volts. At position B the pointer indicates a voltage of 75 volts. Since the pointer is halfway between the small scale divisions at position C, it indicates a voltage of 130 plus 1/2 of 5 (130 plus 2.5), or 132.5 volts.

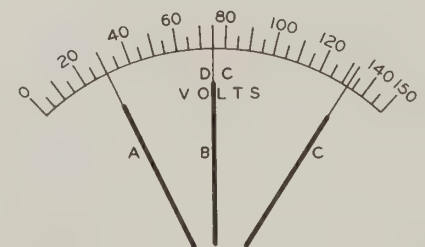


Figure 14

The scale of a dc milliammeter is shown in Figure 15. This scale has a full scale value of .3 milliamperes. On this scale there are nine smaller scale divisions between the major scale divisions. This divides the space between major scale divisions into ten smaller spaces. Therefore, each small scale



Figure 15

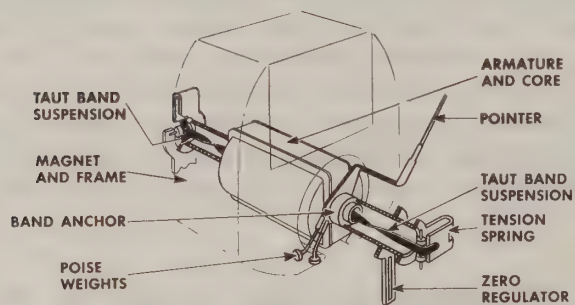
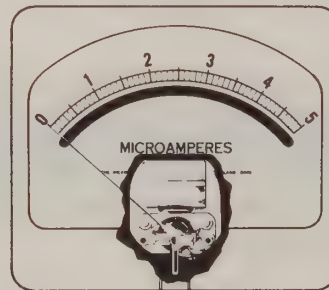
USING ELECTRIC METERS

division has a value of $1/10$ of a major scale division. Since each major scale division has a value of .1 milliampere, each small scale division has a value of $1/10$ of .1, or .01 milliampere.

If the pointer in Figure 15 is at position A, it indicates a current of .05 milliampere. At position B the pointer is about halfway between the .04 and .05 small scale divisions. Thus, it indicates a current of .2 plus .04 plus $1/2$ of .01, or .245 milliampere. At position C the pointer indicates a current of .3 milliampere.

CHOOSING THE CORRECT METER

The maximum voltage or current that a meter can measure is its full scale value. Thus, if a voltmeter can measure from 0 to 150 volts, you should never try to measure a voltage greater than 150 volts. An excessive voltage or current could damage the delicate mechanism in the meter. When in doubt, use a meter with a very high full scale value. You can always change to another meter if the voltage or current is lower.



This illustration shows the internal construction of a taut band suspension meter movement.

Courtesy Hickok Electric Co.

A current meter with a scale of 0 to 10 amperes cannot accurately measure currents near 0 ampere. Refer back to the scale shown in Figure 12. The first small scale division to the right of the 0 mark has a value of .2 ampere. Thus, if .2 ampere is applied to the meter, the pointer only deflects to the first small scale division to the right of zero. If a current less than .2 ampere is applied, the pointer might not even move off the 0 mark.

As a general rule, a meter cannot display a current or voltage lower than the value of one small scale division. To measure a current or voltage lower than the value of one small scale division, you must use a more sensitive meter. Try to choose a meter that has a center scale value close to the value of voltage or current you wish to measure. Then, if the voltage or current is a little higher or lower, you will still be able to measure it, using the same meter.

USING AC METERS

Alternating current (ac) continuously changes direction in a circuit. Likewise, an ac voltage is constantly changing polarity. AC voltage and current can only be measured by meters designed especially to measure ac. You connect ac meters exactly the same way as dc meters. An ac ammeter is connected in series with a circuit so that the current to be measured flows through the meter. An ac voltmeter is connected between or in parallel with the points across which the voltage exists.

Since an alternating current is constantly changing direction and an ac voltage is constantly changing polarity, ac meters do not have any fixed polarity. **YOU DO NOT HAVE TO OBSERVE POLARITY WHEN CONNECTING AC METERS INTO A CIRCUIT.** In general, the scales on ac meters are similar to those on dc meters, and you read them similarly.

HOW TO USE AN OHMMETER

The resistance of a circuit or component can be measured by using an **OHMMETER**. An ohmmeter measures resistance by applying a known voltage to the circuit or component under test, and measuring the resulting current. The voltage for the ohmmeter is usually supplied by batteries or a built-in power supply. With a constant voltage applied to the meter circuit, the current, and thus the deflection of the meter pointer, varies with the resistance being measured. The meter scale is calibrated in ohms.

To measure the resistance of a component or circuit, just connect the ohmmeter across the circuit or component. Figure 16 shows how an ohmmeter is connected to measure the resistance of a resistor. Note that

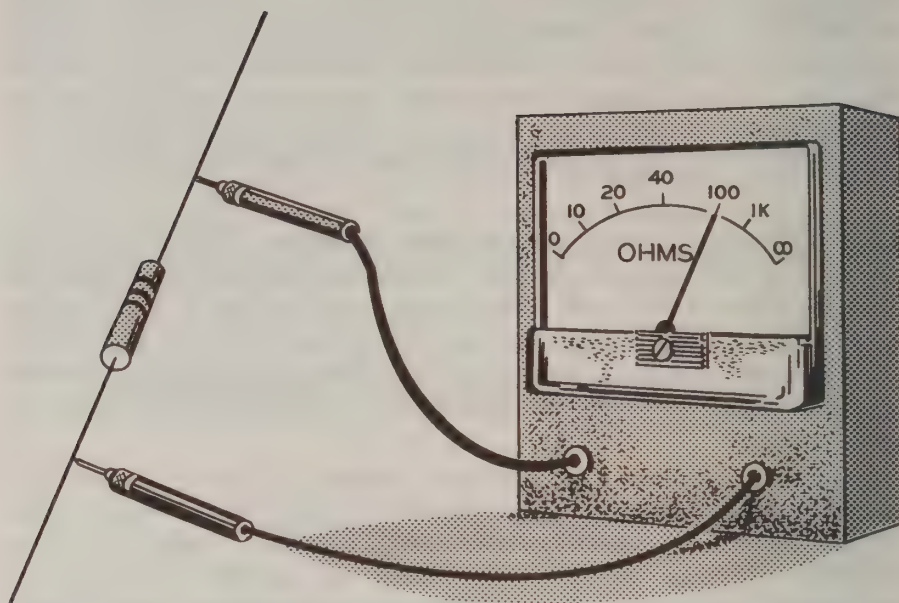


Figure 16

the ohmmeter is connected across or in PARALLEL with the resistor. Figure 17 shows the symbol commonly used for an ohmmeter.

There are two precautions which must be observed when connecting an ohmmeter into a circuit. First, make sure the power source of the circuit is turned off. Disconnect the equipment from the source of power, if possible. Second, when measuring the resistance of a single component, disconnect one end of the component from the circuit. This will eliminate parallel paths which would give an incorrect resistance reading. You might use a voltmeter to measure the circuit to make sure that no voltage is present before a resistance measurement is performed.

Figure 18A shows the WRONG way to connect an ohmmeter to measure the resistance of R_3 . With supply E_s still connected, a voltage is present across R_3 which could damage the ohmmeter. Also, since R_2 is in parallel with R_3 , you would be measuring the combined resistance of R_2 and R_3 , instead of the resistance of R_3 alone.

Figure 18B shows the RIGHT way to measure the resistance of R_3 . Notice that supply E_s has been disconnected. Also note that one end of R_3 is disconnected from the circuit so that the meter measures only the resistance of R_3 .



Figure 17

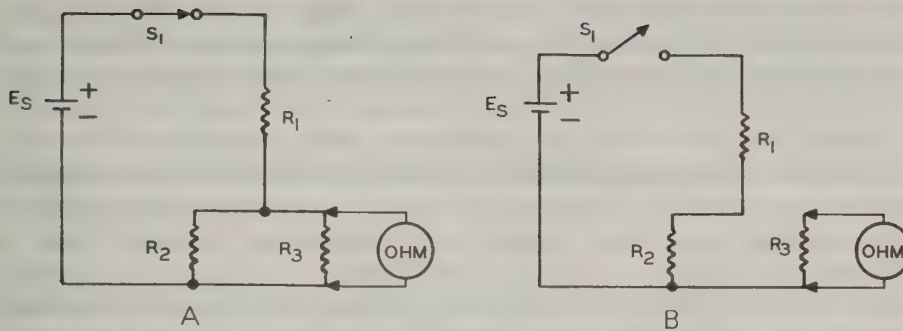


Figure 18

READING OHMMETERS

Ohmmeter scales are different from the ammeter and voltmeter scales described earlier. Figure 19 shows a typical ohmmeter scale. This scale is read from left to right, just as you would read an ammeter or voltmeter scale. However, unlike the ammeter and voltmeter scales, the values of the major scale divisions are not the same at all points on the scale. The major scale divisions at the left have values of 5 ohms. Between the 20 and 60 marks, each major division has a value of 10 ohms. At the right, between the 200 and 1K marks, each major division has a value of 100 ohms. Also note that the major scale divisions are not equally spaced.

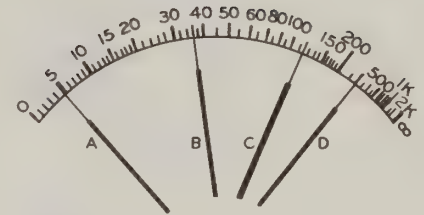


Figure 19

This scale is called a **NONLINEAR SCALE**. The ammeter and voltmeter scales described earlier have equally spaced divisions, and are called **LINEAR SCALES**. The nonlinear scale is characteristic of an ohmmeter. However, some ammeters and voltmeters also have nonlinear scales.

Even though the ohmmeter scale is nonlinear, it is still easy to read. Since the values of the major scale divisions are not the same at all points on the scale, the small scale divisions also have different values. To determine the value of a small scale division, look at the value of the major scale division on either side. Then determine the value of the small scale division as you would on a linear ammeter or voltmeter scale.

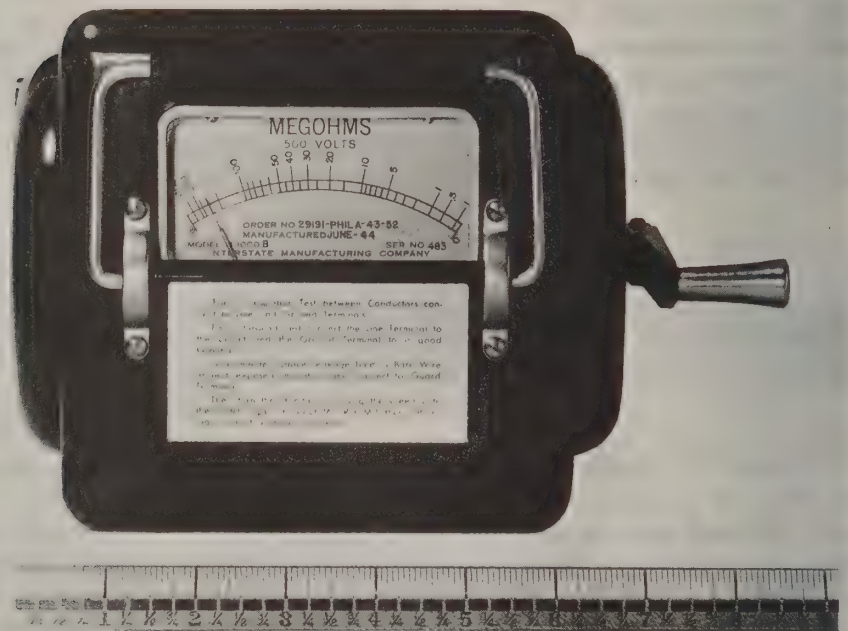
For example, let's determine the values of the small scale divisions between the 10 and 15 marks. At this point on the scale, the distance between the two major scale divisions represents a value of 5 ohms. Since there are four small scale divisions which divide the space between major scale divisions into five parts, each small scale division has a value of $1/5$ of 5 ohms, or 1 ohm. As another example, determine the value of the small

USING ELECTRIC METERS

scale division between the 50 and 60 marks. Since there is only one small scale division, its value is equal to $1/2$ of 10 ohms, or 5 ohms. You can use the same procedure to determine the values of the other small scale divisions.

Assume the pointer is at position A, as shown in Figure 19. At this position the pointer indicates a resistance of 5 ohms. At position B the pointer is over the third small scale division to the right of the 30 mark. Thus, it indicates a resistance of 30 plus 6, or 36 ohms. At position C the pointer is about halfway between the 110 and 120 ohm marks, and thus indicates a resistance of 115 ohms. At position D, the pointer indicates a resistance of 300 ohms. The 300- and 400-ohm major division marks are not labeled since the scale is too crowded at this point.

The last mark on the right side is labeled ∞ , which means infinity. If the pointer deflects to this position, the resistance being measured is considered beyond the range of the meter, being too high to be measured with this meter.



This ohmmeter, referred to as a "MEGGER," is used to measure very high (as high as 1000 megohms) resistances.

Courtesy Winslow Electronics Inc.

In an ohmmeter with a scale similar to the one shown in Figure 19, the pointer normally rests on the ∞ mark when no resistance is being measured.

This is because there is infinite resistance, an open circuit, between the test leads when they are not touching anything. If you short the ohmmeter test leads together, the pointer should deflect to the 0 mark to indicate zero ohms between the test leads. Most ohmmeters of this type have an OHMS ADJUST control. Before using the meter, you adjust this control so that the ohmmeter reads ∞ when the test leads are not touching. This procedure is shown in Figure 20.

Figure 21 shows another ohmmeter scale. This scale is different than the one shown in Figure 19. Notice that it is read from right to left, whereas the scale shown in Figure 19 is read from left to right. An ohmmeter with the scale shown in Figure 21 is usually referred to as a **SERIES-TYPE OHM-METER**. An ohmmeter with the scale shown in Figure 19 is referred to as a **PARALLEL-TYPE** or **BACK-UP TYPE OHMMETER**. You read the scale shown in Figure 21 in the same manner as you do the scale of Figure 19. However, as indicated above this scale, the numbered values must be multiplied by 1000. Thus, "500" represents 500,000 ohms, "100" represents 100,000 ohms, and so on.

Assume that the pointer of the ohmmeter is at position A, as shown in Figure 21. Here the pointer is over the 200 mark and it indicates a resistance of 200×1000 , or 200 k Ω . At position B, the pointer indicates a resistance of 30×1000 , or 30 k Ω . In position C the indicated resistance is 5 k Ω , and in position D the indicated resistance is 1.5 k Ω .

A series ohmmeter is adjusted differently than a back-up ohmmeter. To adjust the series ohmmeter shown in Figure 21, short the test prods together and adjust the OHMS ADJUST control so that the pointer deflects to the zero mark. With the test prods held apart, the pointer should rest on the infinity (∞) mark. This procedure is shown in Figure 22.

The series and the parallel or back-up ohmmeter can be designed to measure any range of resistance that is desired. However, the back-up ohmmeter is usually used to measure low resistances while the series ohmmeter is more often used to measure high resistance.

MULTIMETERS

The engineer and technician must make many measurements when repairing or building a piece of electronic equipment. If a different voltmeter, ammeter or ohmmeter were used to measure each of the various quantities that might be encountered, a large number of meters would be needed. To

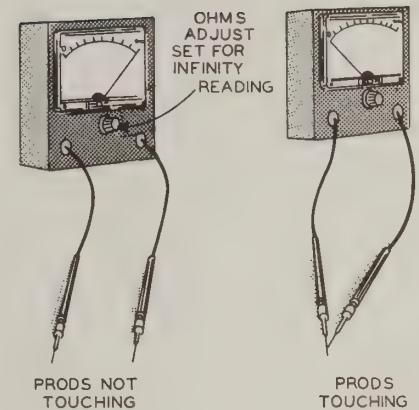


Figure 20

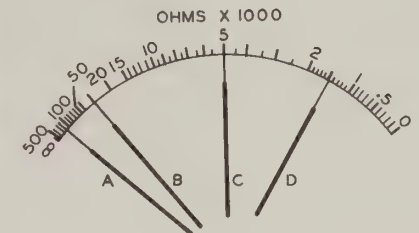


Figure 21

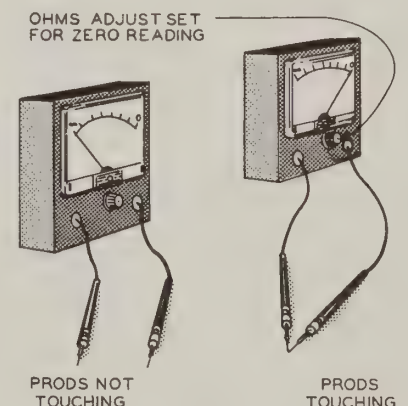


Figure 22

USING ELECTRIC METERS

eliminate the need for several separate meters, the functions of an ammeter, a voltmeter and an ohmmeter can be combined into a single instrument called a **MULTIMETER**. Often a multimeter is called a **VOLT-OHM-MILLIAMMETER (VOM)** when the current scale is calibrated in milliamperes.

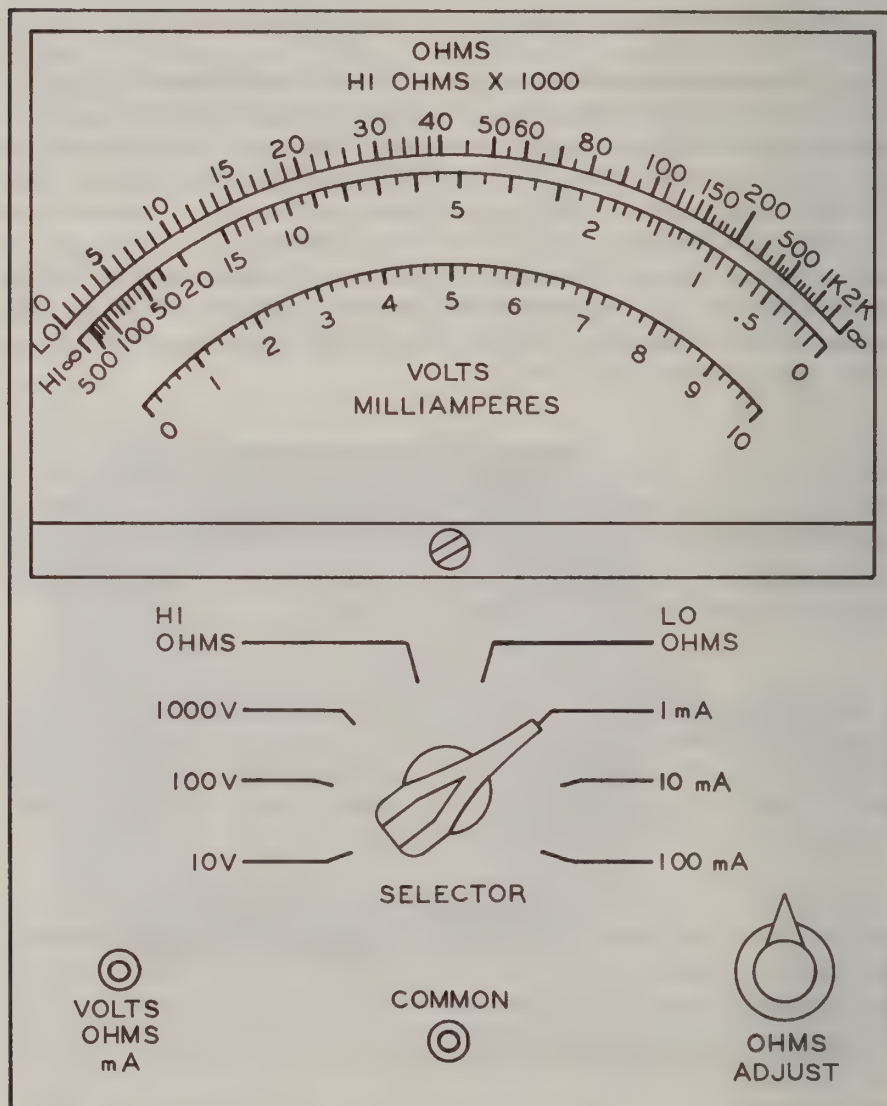


Figure 23

Figure 23 shows the scale and panel of a typical multimeter. This meter has three dc voltage ranges, three dc current ranges and two resistance ranges. There are three scales on the meter to accommodate the various ranges and

The following Practice Exercise questions cover the subjects which you have just studied. They are:

READING AMMETERS AND VOLTMETERS

CHOOSING THE CORRECT METER

USING AC METERS

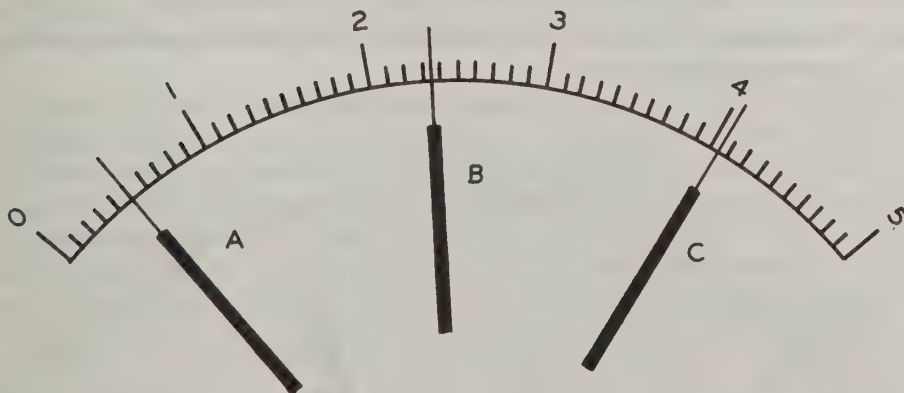
HOW TO USE AN OHMMETER

READING OHMMETERS

16. What values of current are represented by the pointer position on the ammeter scale shown below?

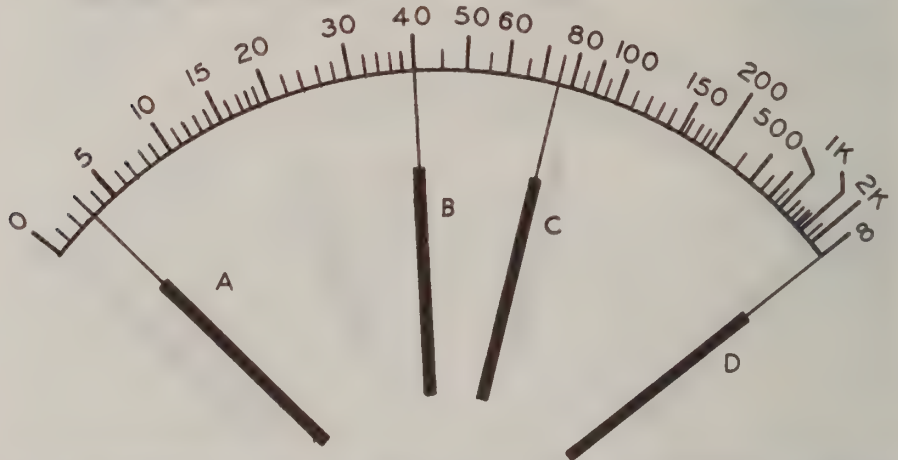


17. What values of voltage are represented by the pointer positions on the voltmeter scale shown below?

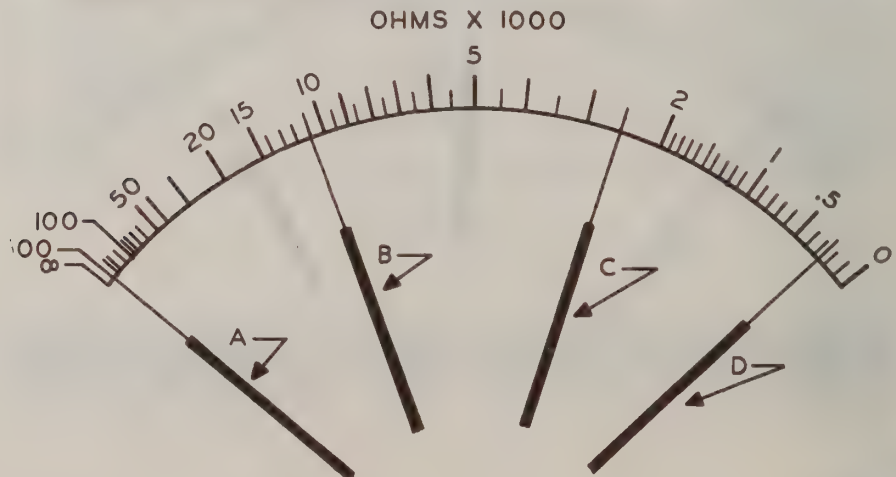


18. Would you use the voltmeter of Figure 14 to measure a voltage near 180 volts?

19. What is the lowest value of current that the meter shown in Figure 15 can measure?
20. Would you damage the meter shown in Figure 15 if you tried to measure .9 microampere?
21. How would you connect an ac ammeter into a circuit? Would you observe polarity?
22. An ohmmeter is connected in parallel with a component to measure its resistance. True or False?
23. What precautions should you observe when measuring the resistance of a resistor in a circuit?
24. An ohmmeter has (a) a linear scale, (b) a nonlinear scale.
25. What values of resistance are indicated by the pointer positions on the ohmmeter shown below?



26. The ohmmeter shown in Figure 19 is a (a) series ohmmeter, (b) back-up ohmmeter.
27. What does an ohmmeter reading of ∞ mean?
28. What values of resistance are indicated by the pointer positions on the ohmmeter shown below?



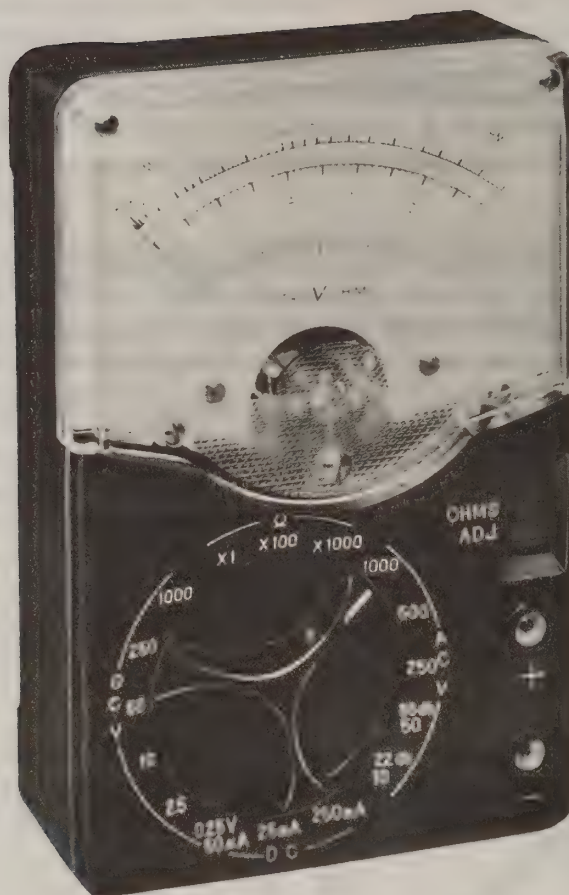
functions. The 0 to 10 scale is used for direct current and voltage measurements while the two ohms scales are used for the two resistance ranges. The selector switch on the multimeter selects the desired voltage, current or resistance range. The OHMS ADJUST control is used to adjust the ohmmeter circuit. The test leads are connected to the COMMON (negative) and the VOLTS-OHMS-mA (positive) jacks.

There are three dc voltage ranges on this multimeter: 0 to 10 volts, 0 to 100 volts and 0 to 1000 volts. The selector switch selects the desired range and the 0 to 10 scale is used for all three ranges. When the selector switch is in the 10V position, the meter can measure from 0 to 10 volts. In this range the voltage is read directly from the 0 to 10 scale. When the selector switch is in the 100V position, the meter can measure from 0 to 100 volts. However, the reading obtained from the 0 to 10 scale must be multiplied by 10 when the meter is on the 100V range. For example, if a reading of 3.5 is obtained, it must be multiplied by 10 to obtain 35 volts. The meter can measure from 0 to 1000 volts when the selector switch is in the 1000V position. However, the readings obtained from the 0 to 10 scale must be multiplied by 100 on the 1000V range. Thus, a reading of 3.5 on this range represents a voltage of 350 volts.

When measuring an unknown voltage, always switch the meter to the highest range, 1000V for this multimeter. Then, if the voltage is much lower, you can switch to a lower range. This procedure will protect the meter from damage.

This multimeter contains two separate ohmmeter circuits. When the selector switch is in the LO OHMS position, the ohmmeter operates in the parallel or back-up fashion. You read the LO scale directly when the selector switch is in this position. With the selector switch set to LO OHMS, the meter can measure resistance between 0 and 2K (2000) ohms.

To measure higher resistances, turn the selector switch to the HI OHMS position. The ohmmeter then operates in the series fashion. You read the HI scale when the selector switch is in the HI OHMS position. All the readings on the HI scale must be multiplied by 1000, as noted at the top of the meter. Thus, if the pointer deflects to .5, the resistance is $.5 \times 1000$, or 500 ohms. If the pointer deflects to 500, the resistance is 500×1000 , or 500,000 ohms. With the selector switch set to HI OHMS, the meter can measure resistances up to 500,000 ohms. You should select the ohmmeter range that will put the pointer near the center of the scale. This provides the most accurate readings. It is also good practice to switch from the ohms function to either voltage or current function when the meter is not in use. This will provide longer ohmmeter battery life.



Pocket volt-ohm-milliammeters are very popular with service technicians. These meters can be carried from job to job.

*Courtesy Eico Electronics
Instrument Co., Inc.*

Three current ranges (0 to 1 mA, 0 to 10 mA and 0 to 100 mA) are also provided on the multimeter shown in Figure 23. The selector switch is used to select the desired range, and current measurement is read from the 0 to 10 scale. When the selector switch is set to the 1 mA position, currents between 0 and 1 mA can be measured. Since the scale reads from 0 to 10, you must divide the reading on the scale by 10. For example, if the pointer deflects to 4, the current is 1/10 of 4, or .4 mA. If the pointer deflects to 9.8, the current is 1/10 of 9.8 or .98 mA, and so on.

When the selector switch is set to 10 mA, the meter can measure currents between 0 and 10 mA. You read the 0 to 10 scale directly on this range. If the selector switch is set to 100 mA, the meter can measure currents from

0 to 100 mA. You still use the 0 to 10 scale, but for this range you multiply the readings by 10. For example, if the pointer stops at 5, the current is 5×10 , or 50 mA. If the pointer stops at 7.7, the current is 7.7×10 , or 77 mA.

When measuring an unknown current, always set the selector switch to its highest setting, 100 mA for this multimeter, to protect the meter. Then switch to a lower range if necessary.

TRANSISTORIZED ELECTRONIC METER

Figure 24 shows a transistorized electronic meter, called a TRVM. This meter is similar to the multimeter in that it can measure voltage, current and resistance. However, the use of transistorized electronic circuits permits a wider range of measurements and also protects the meter movement against electrical damage. In addition, the use of electronic circuits reduces the loading effects of the meter when voltages are measured. Electronic meters which use vacuum tubes are referred to as vacuum tube voltmeters, VTVM's. This transistorized meter is battery operated, permitting greater portability than is possible with most VTVM's, which normally must be plugged into a 110V ac source.

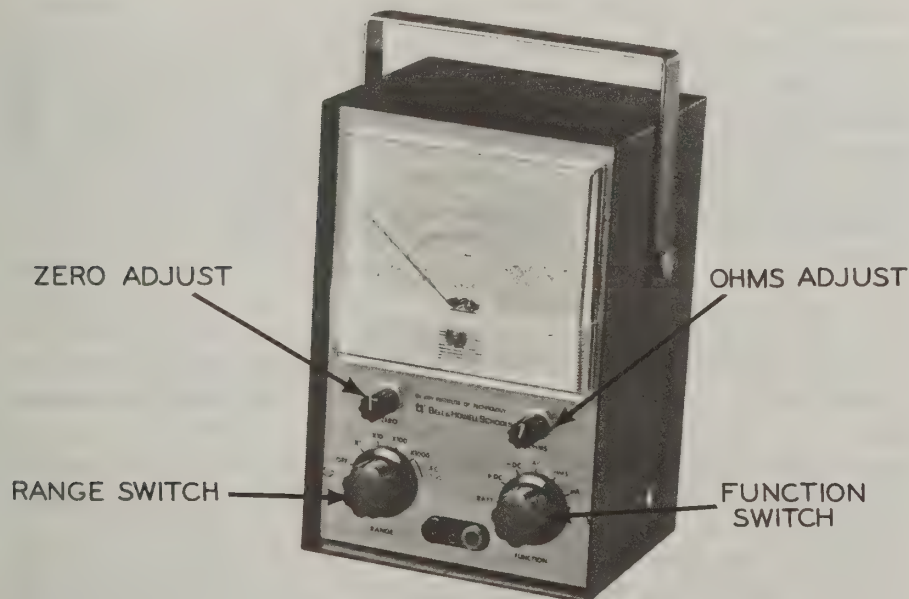


Figure 24

The FUNCTION switch (large lower right-hand knob) changes the meter circuit so it can measure direct current, resistance and ac or dc voltages. The BATT setting of the FUNCTION switch permits the meter to check its internal batteries. The RANGE switch (large lower left-hand knob) turns the meter on and selects the desired range.

When you turn the meter on, set the ZERO ADJUST control so that the pointer is over the 0 mark at the left edge of the scales. This balances the transistorized circuits in the meter. Mechanical zero adjustment of the meter movement (which is rarely necessary) can be made with the small adjustment screw when the meter is turned off. The electrical zero adjustment should be made whenever the meter is used.

How to Measure Voltage

To measure a dc voltage, the FUNCTION switch is set to +DC or —DC. These two dc settings permit the meter's polarity to be reversed without reversing the test leads. This is a timesaver when voltages which are positive and negative with respect to some reference point must be measured. With the FUNCTION switch at the +DC position, the common test jack (black) is negative and the red test jack is positive. However, when the FUNCTION switch is at the —DC position, the common test jack (black) is positive and the red test jack is negative.

The RANGE switch can be set to one of four positions: $\times 1$, $\times 10$, $\times 100$ or $\times 1000$ for the dc voltage measurements. When measuring ac, the highest range is $\times 200$. These positions change the range of voltages the meter can measure. The dc volts scale, which goes from 0 to 1, is used for all dc ranges. The numbers $\times 1$, $\times 10$, $\times 100$ and $\times 1000$ are called multipliers, and are used to multiply the scale readings for the various ranges.

When the RANGE switch is in the $\times 1$ position, the multiplier for the 0 to 1 dc volts scale is 1, and you read the scale directly. The meter can measure from 0 to 1 volt dc with the RANGE switch in this position. To measure higher voltages, set the RANGE switch to the $\times 10$ position. In this position you multiply all the scale readings by 10 and the meter can measure from 0 to 10 volts dc. With the RANGE switch in the $\times 100$ position, you multiply all the scale readings by 100, and the meter can measure from 0 to 100 volts. When the RANGE switch is in the $\times 1000$ position, you multiply the scale readings by 1000, and the meter can measure from 0 to 1000 volts.



Figure 25

Figure 25 shows the transistorized meter scale in greater detail. To show how you would read the dc volts scale, assume that the pointer is at position A. In this position a reading of .34 is obtained. If the RANGE switch is set at $\times 1$, this reading represents $.34 \times 1$, or .34 volt. With the RANGE switch set at $\times 10$, this same reading represents $.34 \times 10$, or 3.4 volts. If the RANGE switch is set at $\times 100$, this reading represents $.34 \times 100$, or 34 volts, and so on.

To measure an ac voltage, set the FUNCTION switch to the AC position and read the values from the 0 to 5 ac volts scale. The RANGE switch again determines the range of voltages the meter can measure. In the $\times 1$ position, the multiplier for the 0 to 5 ac volts scale is 1 and you read the scale directly. When the RANGE switch is in the $\times 10$ position, you multiply the scale readings by 10 and the meter can measure from 0 to 50 volts. With the RANGE switch in the $\times 100$ position, you multiply the scale readings by 100 and the meter can measure from 0 to 500 volts. The last RANGE switch setting when measuring an ac voltage is $\times 200$. The $\times 1000$ multiplier is not used for an ac voltage. Thus, with the RANGE switch in the $\times 200$ position, you multiply the scale readings by 200. The meter then measures from 0 to 1000 volts.

As an example of reading the ac scale, assume the pointer is at position B in Figure 25. If the RANGE switch is set at $\times 1$, 3×1 , or 3 volts will be represented. With the RANGE switch set at $\times 10$, 3×10 , or 30 volts will be represented. When the RANGE switch is set at $\times 100$, 3×100 , or 300 volts will be represented. If the RANGE switch is set at $\times 200$, 3×200 , or 600 volts will be represented.



This electronic volt-ohm-milliammeter employs solid state circuits. The internal battery supply makes the unit as portable as a conventional VOM.

Courtesy Simpson Electric Co.

How to Measure Current

To measure a direct current, set the FUNCTION switch to μA and read the 0 to 50 μA (microampere) scale. Note that this scale is calibrated in microamperes ($1 \mu\text{A} = .000001$ ampere). When the RANGE switch is at the $\times 1$ position, you read the scale directly. In the $\times 10$ position you multiply the scale readings by 10. In the $\times 100$ position you multiply the scale readings by 100, and in the $\times 1000$ position you multiply the scale readings by 1000.

Figure 25 shows the μA scale in greater detail. Assume that the pointer is at position B. The reading on the μA scale is 29. If the RANGE switch is in the $\times 1$ position, 29×1 , or 29 μA will be represented. When the RANGE switch is in the $\times 10$ position, 29×10 , or 290 μA will be represented. With the RANGE switch in the $\times 100$ position, 29×100 , or 2900 μA (2.9 mA) will be represented.

How to Measure Resistance

To measure resistance with the meter shown in Figure 24, set the FUNCTION switch to OHMS and read the OHMS scale. Before making any measurements, you must set the ZERO ADJUST and OHMS ADJUST controls for proper pointer position. With the test leads not touching anything, adjust the ZERO ADJUST control to set the pointer over the ∞ (infinity) mark on the ohms scale. Then you short the test leads together and adjust the OHMS ADJUST control to bring the pointer over the zero mark at the right edge of the scale. When these adjustments are performed, you can begin your resistance measurements.

When the RANGE switch is in the $\times 1$ position, read the ohms scale directly. If the RANGE switch is in the $\times 10$ position, you multiply the scale readings by 10, and so on. Remember to look at the values of the major scale divisions on either side of the smaller scale divisions before determining their values. This is necessary since the ohms scale is nonlinear.

Assume the pointer is at position C in Figure 25. On the ohms scale this is a reading of 35. If the RANGE switch is in the $\times 1$ position, 35×1 , or 35 ohms will be represented. With the RANGE switch in the $\times 10$ position, 35×10 , or 350 ohms will be represented, and so on.

SUMMARY

To measure the current in a circuit, a current meter is connected in series with the circuit so that the current to be measured flows through the meter. A voltmeter is connected between or in parallel with the points across which the voltage exists.

When measuring a direct voltage and current, meter polarity must be observed. A current meter must be connected so that electrons flow from $-$ to $+$ through the meter. Likewise, the $-$ terminal of a voltmeter must be connected to the $-$ point in the circuit and the $+$ terminal of the voltmeter must be connected to the $+$ point in the circuit. However, polarity is not observed when an alternating voltage or current is measured.

The resistance of a circuit or a component is measured by using an ohmmeter. To measure the resistance of a circuit or component, the ohmmeter is connected across the circuit or component. When measuring the resistance of a single component in a circuit, it is a good idea to disconnect one side

USING ELECTRIC METERS

of the component so that other components will not affect the measurement. To protect the ohmmeter, power should be removed from a circuit before a resistance measurement is made.

Often the functions of a voltmeter, a current meter and an ohmmeter are combined into a single instrument called a multimeter. This type of meter can measure a wide range of voltages, currents and resistances. Vacuum tube or transistorized circuits are combined with a multimeter to form an electronic meter.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

MULTIMETERS

TRANSISTORIZED ELECTRONIC METER

HOW TO MEASURE VOLTAGE

HOW TO MEASURE CURRENT

HOW TO MEASURE RESISTANCE

29. If the selector switch on the multimeter shown in Figure 23 is in the 1000V position, what are the values of the major scale divisions on the 0 to 10 scale?
30. To what position should you turn the selector switch on the multimeter shown in Figure 23 if you were measuring an unknown voltage?
31. If you were going to measure a resistance that was close to 10K (10,000) ohms, should you use the HI OHMS or LO OHMS setting on the multimeter shown in Figure 23?
32. Assume you have the meter shown in Figure 23 set on the 10 mA range. If the pointer deflects to the right, off scale, when you measure an unknown current, should you switch to a higher or lower range?
33. What is the purpose of the ZERO ADJUST control on the transistorized meter shown in Figure 24?
34. What is the purpose of the +DC and —DC settings of the FUNCTION switch on the transistorized meter shown in Figure 24?

35. If the RANGE switch is set to $\times 100$ and the pointer is at position B in Figure 25, what is the dc voltage?
36. What is the maximum ac voltage you can measure with the transistorized meter shown in Figure 24?
37. If the RANGE switch is set to $\times 200$ and the pointer is at position C in Figure 25, what is the ac voltage being measured?
38. What is the maximum dc current that the transistorized meter shown in Figure 24 can measure?
39. With the pointer at position A in Figure 25 and the RANGE switch at $\times 100$, what value of dc current is indicated?
40. If you were going to measure an unknown current with the meter shown in Figure 24, what RANGE switch setting would you use?
41. With the transistorized meter shown in Figure 24, could you measure a resistance of $200\text{ k}\Omega$ with the RANGE switch at $\times 1$?
42. Is it necessary that power be removed from a circuit before resistance measurements are made?
43. With the pointer at position B in Figure 25, and the RANGE switch at $\times 1000$, what resistance is indicated?

IMPORTANT DEFINITIONS

AMMETER — An instrument designed to measure current in amperes.

DEFLECTION — The amount of pointer movement in an electric meter.

ELECTRIC METER — An electromechanical current-measuring instrument.

ELECTRONIC METER — A combination of an electric meter and an electronic circuit which operates the electric meter.

FULL SCALE — The maximum value a meter can indicate.

KILOVOLTMETERS — Instruments designed to measure voltage in kilovolts.

LINEAR SCALES — Uniformly divided scales where corresponding divisions are the same distance apart.

MICROAMMETER — An instrument designed to measure current in microamperes.

MICROVOLTMETERS — Instruments designed to measure voltage in microvolts.

MILLIAMMETER — An instrument designed to measure current in milliamperes.

MILLIVOLTMETERS — Instruments designed to measure voltage in millivolts.

MULTIMETER — A single instrument which combines the functions of a voltmeter, an ammeter and an ohmmeter.

NONLINEAR SCALE — A nonuniformly divided scale where scale divisions do not have equal value at all points on the scale.

OHMMETER — An instrument designed to measure the resistance of a circuit or component.

VOLTMETER — An instrument designed to measure voltage in volts.

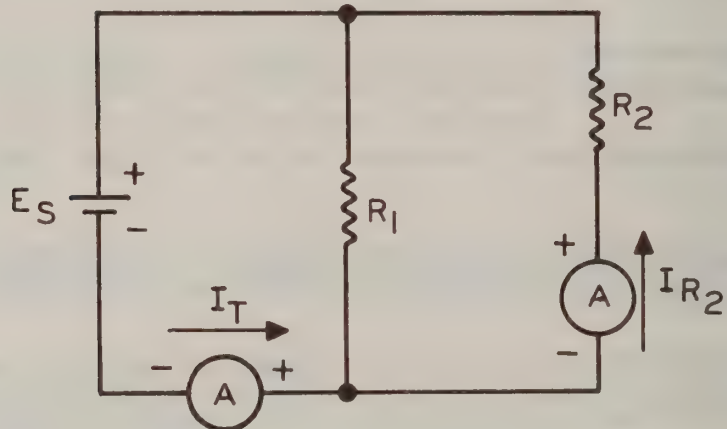
VOLT-OHM-MILLIAMMETER (VOM) — A multimeter which measures voltage in volts, resistance in ohms and current in milliamperes.

PRACTICE EXERCISE SOLUTIONS

1. With the meter not connected to a circuit, slowly turn the zero adjust screw until the pointer is directly over the zero mark on the scale.
2. (a) in series with a circuit.
3. The pointer would deflect to the left, off scale, and the meter might be damaged.
4. Usually the red terminal is positive and the black terminal is negative.
5. 3 amperes. — To solve this problem, use the form of Ohm's Law $I = E/R$. The circuit current is then equal to:

$$I = E/R = 60 \text{ volts} \div 20 \text{ ohms} = 3 \text{ amperes.}$$

6.



7. Of the three, the microammeter is the most sensitive. The milliammeter is less sensitive than the microammeter but is more sensitive than the ammeter.

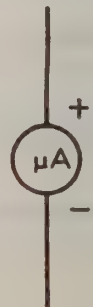
8.



AMMETER



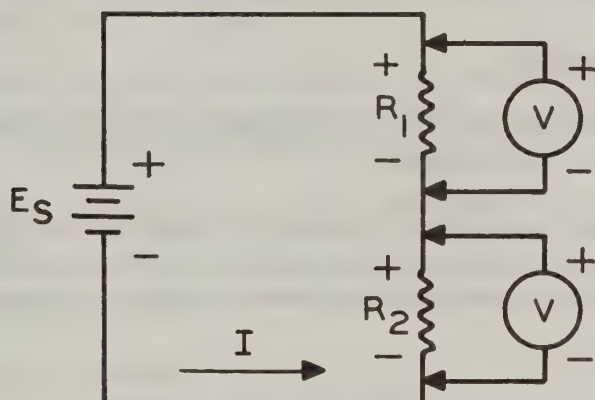
MILLIAMMETER



MICROAMMETER

PRACTICE EXERCISE SOLUTIONS (Continued)

9. The meter with an internal resistance of 50 ohms would cause the smallest change in the resistance of the circuit under test, and would therefore have the least effect on the circuit.
10. True
11. Yes — The negative voltmeter terminal must be connected to the more negative point in the circuit, and the positive terminal must be connected to the more positive point.
- 12.



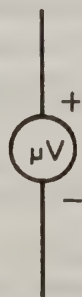
13. You would probably use a kilovoltmeter.
- 14.



VOLTMETER



KILOVOLTMMETER



MICROVOLTMMETER

15. You would want a voltmeter with a very high internal resistance. For this application you would probably choose an electronic voltmeter.

PRACTICE EXERCISE SOLUTIONS (Continued)

16. A = .4 ampere
B = 3.7 amperes
C = 7 amperes
D = 9.9 amperes.
17. A = .5 volt
B = 2.35 volts
C = 4.05 volts.
18. No — This meter can measure a maximum value of 150 volts. Applying 180 volts would possibly damage the meter.
19. .01 milliampere.
20. No — This low value of current probably would not even move the pointer off the zero mark.
21. You would connect the ac ammeter in series with the circuit so that the current to be measured flows through the meter. Since an ac meter has no polarity, you would not observe polarity when connecting it.
22. True
23. You should first disconnect any voltage source. Then you should disconnect one end of the resistor to be sure you are not measuring any other resistance in the circuit.
24. (b) a nonlinear scale.
25. A = 3 ohms
B = 40 ohms
C = 75 ohms
D = ∞ — It is beyond the range of this meter.
26. (b) back-up ohmmeter.
27. A reading of ∞ (infinity) means that the resistance is too high to be measured by this ohmmeter.
28. A = 500 k Ω
B = 11 k Ω
C = 2.5 k Ω (2500 ohms)
D = .25 k Ω (250 ohms).

PRACTICE EXERCISE SOLUTIONS (Continued)

29. Each major scale division has a value of 100 volts. On the 1000V range, the scale indications are multiplied by 100. Thus, the first major division is 100, the second is 200, and so on to a full scale reading of 1000.
30. You should set the selector switch to the 1000V position to protect the meter. If the voltage being measured is less than 100V, you would then switch to a lower range.
31. You should use the HI OHMS setting since the LO OHMS setting only allows you to measure up to 2K (2000) ohms.
32. You should quickly switch to a higher range since the current you are measuring deflects the pointer off scale.
33. The ZERO ADJUST control balances the transistor circuits in the meter, and thus is used to position the pointer over the zero mark on the scale when the meter is turned on.
34. The +DC and —DC positions permit the polarity of the meter to be reversed.
35. $.58 \times 100$, or 58 volts.
36. 5×200 , or 1000 volts.
37. 3.8×200 , or 760 volts.
38. 50×1000 , or 50,000 μA (50 mA).
39. 17×100 , or 1700 μA (1.7 mA).
40. To protect the meter, you would probably start with the meter set on the $\times 1000$ range.
41. No — You can only measure up to about 10 k Ω on the $\times 1$ range.
42. Yes — If power is applied to the circuit, the meter may be damaged.
43. About 72.5×1000 , or 72.5 k Ω .

1. The first part of the document is a list of the names of the members of the committee.

2. The second part of the document is a list of the names of the members of the committee.

3. The third part of the document is a list of the names of the members of the committee.

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16. The sixteenth part of the document is a list of the names of the members of the committee.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE
1016A

Example:

A	☐
B	☒
C	☐
D	☐

The sun rises in the

A. south. B. east. C. west. D. north.

1. A ☐ **A dc ammeter is connected**
 B ☐ (A) across the circuit. (B) so electrons flow out of the — terminal. (C) in series
 C ☐ with a circuit. (D) in parallel with a circuit.
 D ☐
2. A ☐ **A dc voltmeter is connected**
 B ☐ (A) between or in parallel with the points where the voltage appears. (B) just like
 C ☐ an ammeter. (C) so electrons flow out of the — terminal. (D) so electrons flow
 D ☐ into the + terminal.
3. A ☐ **When connecting an AC CURRENT meter,**
 B ☐ (A) it must be connected with its — terminal to the negative terminal of the source.
 C ☐ (B) it must be connected in parallel. (C) polarity need not be observed. (D) it must
 D ☐ be connected with its + terminal to the negative terminal of the source.
4. A ☐ **A voltmeter**
 B ☐ (A) should provide a very low resistance across the resistance being measured. (B)
 C ☐ should have a very high internal resistance. (C) with an infinite internal resistance
 D ☐ would cause severe circuit loading. (D) with a very low internal resistance would
 be very accurate.
5. A ☐ **The full scale value of a voltmeter or ammeter indicates**
 B ☐ (A) the value of a small scale division. (B) the value of a major scale division.
 C ☐ (C) the minimum value of voltage or current the meter can measure. (D) the
 D ☐ maximum value of voltage or current the meter can measure.
6. A ☐ **If the meter pointer in Figure 12 deflects to a point halfway between the first and**
 B ☐ **second small scale divisions to the right of the 6 mark, the current is**
 C ☐ (A) 5.65 amperes. (B) 5.5 amperes. (C) 6.4 amperes. (D) 6.3 amperes.
 D ☐
7. A ☐ **The ohmmeter scale shown in Figure 21 is**
 B ☐ (A) linear. (B) for a parallel ohmmeter. (C) nonlinear. (D) for a back-up ohm-
 C ☐ meter.
 D ☐
8. A ☐ **When connecting an ohmmeter to measure the resistance of a circuit,**
 B ☐ (A) power should be removed from the circuit. (B) the ohmmeter is connected in
 C ☐ series with the circuit. (C) power should be applied to the circuit. (D) make sure
 D ☐ that only ac current is flowing in the circuit.
9. A ☐ **If the FUNCTION switch of the meter of Figure 24 is at μA and the RANGE**
 B ☐ **switch is at $\times 100$, what is the current if the pointer is at the second small scale**
 C ☐ **division to the right of the 25 mark on the μA scale?**
 D ☐ (A) 25.7 amperes. (B) 2700 μA . (C) 27 amperes. (D) 35 mA.
10. A ☐ **The OHMS ADJUST control on the meter of Figure 24 is**
 B ☐ (A) adjusted when current is being measured. (B) adjusted to bring the pointer
 C ☐ over zero when dc voltage is being measured. (C) only used when ac voltage is
 D ☐ measured. (D) adjusted so that the pointer is at zero when the test leads are shorted.

ELECTRICAL PROBLEM SOLVING

1019

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The technician must often call upon his electrical problem-solving ability when troubleshooting electronic equipment.

Courtesy Motorola Inc., Military Electronic Div.

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Thank God every morning when you get up that you have something to do that day which must be done, whether you like it or not. Being required to work, and forced to do your best, will breed in you temperance and self-control, diligence and strength of will, cheerfulness and content, and a hundred virtues which the idle never know.

—Charles Kingsley

ELECTRICAL PROBLEM SOLVING

While studying electronics, it will become necessary to solve some simple problems involving Ohm's Law. Problem solving can be as EASY or as difficult as you make it. By using the correct techniques, you will be surprised at how easily problems can be solved.

SCIENTIFIC NOTATION

All of us are always on the lookout for "short cuts" to ease our work. We have many of these available to us for our use in problem solving. Let's consider a typical Ohm's Law problem. Assume a circuit has a resistance of 100 k Ω (100,000 ohms) and the circuit current is 400 μ A (.0004 ampere). Using the form of Ohm's Law, $E = IR$, we would determine the voltage as follows:

$$\begin{aligned} E &= IR \\ &= .0004 \text{ ampere} \times 100,000 \text{ ohms} \\ &= 40 \text{ volts.} \end{aligned}$$

The major difficulty in solving a problem similar to this one is keeping track of the zeros and decimal points to arrive at the correct answer. This can be done quite simply by employing **SCIENTIFIC NOTATION**. When a number is written with an **EXPONENT**, such as 4^2 , the exponent (2) indicates how many times the number is to be multiplied by itself. Thus, $4^2 = 4 \times 4 = 16$. Scientific notation involves the use of exponents of the number 10. The following chart lists the values of 10 with several different exponents:

$$\begin{aligned} 10^0 &= 1 \\ 10^1 &= 10 \\ 10^2 &= 10 \times 10 = 100 \\ 10^3 &= 10 \times 10 \times 10 = 1,000 \\ 10^4 &= 10 \times 10 \times 10 \times 10 = 10,000 \\ 10^5 &= 10 \times 10 \times 10 \times 10 \times 10 = 100,000 \\ 10^6 &= 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1,000,000. \end{aligned}$$

The first and second entries in the chart are special entries. Any number with an exponent of 0 is equal to 1. Thus: $10^0 = 1$, $5^0 = 1$, $7^0 = 1$ and $256^0 = 1$. Any number with an exponent of 1 is equal to the number itself. Thus: $10^1 = 10$, $5^1 = 5$, $7^1 = 7$ and $256^1 = 256$.

When dealing with exponents of the number 10, we often call the exponent a **POWER OF TEN**. Let's see how we can use scientific notation to simplify numbers. The resistance in the problem mentioned earlier was 100 k Ω or 100,000 ohms. Since 100,000 equals $10,000 \times 10$ we could write this number as $10,000 \times 10^1$. Since $100,000 = 1,000 \times 100$ we could also write this number as $1,000 \times 10^2$. Actually this number can be written several different ways:

$$100,000 = 10,000 \times 10 = 10,000 \times 10^1$$

$$100,000 = 1,000 \times 100 = 1,000 \times 10^2$$

$$100,000 = 100 \times 1,000 = 100 \times 10^3$$

$$100,000 = 10 \times 10,000 = 10 \times 10^4$$

$$100,000 = 1 \times 100,000 = 1 \times 10^5.$$

All of the preceding methods of expressing the number are correct. However, we are interested in reducing the number of zeros, so the last form, 1×10^5 , is the most desirable. The last form is usually called "scientific notation." The other forms are said to be in terms of "powers of 10." Sometimes the names "scientific notation" and "powers of 10" are used interchangeably.

Instead of remembering that $10^3 = 1000$, we can relate the power of ten, or exponent, to the movement of the decimal point. For example, in the number 50,000 the decimal point is understood to be at the right of the last zero (50,000). Thus, when we convert 50,000 to $5,000 \times 10^1$, we are moving the decimal point one place to the left as shown below:

$$50,000 = 5000.\overset{\curvearrowright}{0} \times 10^1 = 5,000 \times 10^1$$

and similarly:

$$50,000 = 500.\overset{\curvearrowright}{00} \times 10^2 = 500 \times 10^2$$

$$50,000 = 50.\overset{\curvearrowright}{000} \times 10^3 = 50 \times 10^3$$

$$50,000 = 5.\overset{\curvearrowright}{0000} \times 10^4 = 5 \times 10^4.$$

Note that the exponents in the previous examples equal the number of places that the decimal point has been moved to the left. Several other examples follow:

$$100,000 = 1.\underbrace{00000.}_{\text{5 places}} \times 10^5 = 1 \times 10^5$$

$$4,000 = 4.\underbrace{000.}_{\text{3 places}} \times 10^3 = 4 \times 10^3$$

$$4,500 = 4.\underbrace{500.}_{\text{3 places}} \times 10^3 = 4.5 \times 10^3.$$

The third example, $4,500 = 4.5 \times 10^3$, could also be written as 45×10^2 . Either is correct. However, it is found to be more convenient to convert all numbers to a number between 1 and 10, thus expressing them in scientific notation. Although this makes the number a decimal, it is generally easier to work with than leaving it expressed as 45×10^2 .

Conversion of a number expressed in scientific notation is the reverse process. Just move the decimal point to the right the number of places indicated by the exponent. Add zeros as necessary. Several examples follow:

$$4 \times 10^3 = 4.\underbrace{000.}_{\text{3 places}} = 4,000$$

$$6.8 \times 10^2 = 6.\underbrace{80.}_{\text{2 places}} = 680$$

$$3.75 \times 10^5 = 3.\underbrace{75000.}_{\text{5 places}} = 375,000.$$

Scientific notation can also be used to represent numbers that are less than one. This is especially helpful when dealing with decimal numbers such as currents in the mA and μA range. Such a situation exists in the problem where the circuit current is 400 μA or .0004 ampere.

When dealing with numbers greater than 1, we use powers of ten that increase in value such as 10^2 , 10^3 , 10^4 and so on. To work with numbers less than 1, the powers of ten must decrease in value. Let's see how this is done.

Consider the decimal number 0.1. This is equal to $1/10$ when expressed as a fraction. It has been shown that $10 = 10^1$. Thus $.1 = 1/10 = 1/10^1$. This is not really a better way of expressing the number. However, from the basic laws of exponents, we can express $1/10^1$ as 10^{-1} . Thus, $.1 = 10^{-1}$. The following chart illustrates this procedure:

$$.1 = 1/10 = 10^{-1}$$

$$.01 = 1/100 = 10^{-2}$$

$$.001 = 1/1,000 = 10^{-3}$$

$$.0001 = 1/10,000 = 10^{-4}$$

$$.00001 = 1/100,000 = 10^{-5}$$

$$.000001 = 1/1,000,000 = 10^{-6}.$$

Using this arrangement, convert the current of .0004 ampere into scientific notation. Since $.0004 = 4 \times 1/10,000$ we can write .0004 amp as 4×10^{-4} ampere.

A simpler procedure is to count the number of places that the decimal point is moved, as explained for numbers larger than one. When dealing with numbers less than one, the decimal point is moved to the right. For each place that the decimal point is moved to the right, we increase the exponent, or power of ten, by one in a negative direction:

$$.0004 \text{ ampere} = \underline{.0004.} \times 10^{-4} = 4 \times 10^{-4} \text{ ampere.}$$

Thus, in converting .0004 ampere to 4×10^{-4} we move the decimal point four places to the right. Several other examples follow:

$$.0055 = \underline{.005.5} \times 10^{-3} = 5.5 \times 10^{-3}$$

$$.00007 = \underline{.00007.} \times 10^{-5} = 7 \times 10^{-5}$$

$$.0000875 = \underline{.00008.75} \times 10^{-5} = 8.75 \times 10^{-5}$$

$$.015 = \underline{.01.5} \times 10^{-2} = 1.5 \times 10^{-2}.$$

Remember that, in all of the examples shown so far (both positive and negative exponents), the regular number is converted to a number between 1 and 10 times a power of ten, even if a decimal number results.

Conversion of a number expressed in scientific notation with a negative exponent back into a regular number is the reverse process. Just move the decimal point to the left the number of places equal to the negative exponent. To convert 4×10^{-4} ampere back to a regular number, move the decimal point four places to the left since the exponent is minus four:

$$4 \times 10^{-4} = \underline{.0004.} = .0004.$$

The following examples further illustrate the procedure:

$$7.3 \times 10^{-3} = \underline{.007.3} = .0073$$

$$9 \times 10^{-4} = \underline{.0009.} = .0009$$

$$3.75 \times 10^{-6} = \underline{.000003.75} = .00000375.$$

The rules for converting numbers into scientific notation can be summarized as follows:

NUMBERS GREATER THAN 1

TO CONVERT THE NUMBER INTO SCIENTIFIC NOTATION, MOVE THE DECIMAL POINT TO THE LEFT UNTIL YOU HAVE A NUMBER BETWEEN 1 AND 10. THE EXPONENT OF TEN IS EQUAL TO THE NUMBER OF PLACES THE DECIMAL POINT IS MOVED.

TO CONVERT A NUMBER EXPRESSED IN SCIENTIFIC NOTATION WITH A POSITIVE POWER OF TEN, MOVE THE DECIMAL POINT TO THE RIGHT THE NUMBER OF PLACES EQUAL TO THE EXPONENT.

NUMBERS LESS THAN 1

TO CONVERT THE NUMBER INTO SCIENTIFIC NOTATION, MOVE THE DECIMAL POINT TO THE RIGHT UNTIL YOU HAVE A NUMBER BETWEEN 1 AND 10. THE EXPONENT OF TEN IS EQUAL TO THE NUMBER OF PLACES THE DECIMAL POINT IS MOVED AND THE EXPONENT IS GIVEN A NEGATIVE SIGN.

TO CONVERT A NUMBER IN SCIENTIFIC NOTATION WITH A NEGATIVE POWER OF TEN, MOVE THE DECIMAL POINT TO THE LEFT THE NUMBER OF PLACES EQUAL TO THE EXPONENT.



Analysis of the circuits in a complex tape recorder is simplified by employing scientific notation.

Courtesy Roberts, Div. of Rheem Mfg. Co.

The following Practice Exercise questions cover the subject which you have just studied. It is:

SCIENTIFIC NOTATION

1. In the number 2^4 , the 4 is the _____ of the number 2.
2. Scientific notation involves the use of exponents of the number _____.
3. When dealing with exponents of the number 10, the exponent is often called a _____.
4. What are the values of the following numbers? (a) $100^0 =$ _____; (b) $10^7 =$ _____; (c) $5^3 =$ _____.
5. What is the exponent in each of the following? (a) $100 = 10^?$; (b) $25 = 5^?$; (c) $1 = 756^?$.
6. Convert the following numbers to scientific notation. (a) 1,000; (b) 400; (c) 700,000.
7. Convert the following numbers to scientific notation. Express each converted number as a number between 1 and 10. (a) 57,000; (b) 4,700; (c) 9,375; (d) 386.5.
8. Convert the following numbers expressed in scientific notation into regular numbers. (a) 7.6×10^3 ; (b) 6.58×10^1 ; (c) 9.5755×10^5 .

9. Convert the following numbers into scientific notation. (a) .005; (b) .0755; (c) .00000073.
10. Convert the following numbers expressed in scientific notation into regular numbers. (a) 5.5×10^{-3} ; (b) 6×10^{-8} ; (c) 3.75×10^{-1} .
11. To convert 47,000 into scientific notation you would move the decimal point _____ places to the _____.
12. To convert .0068 into scientific notation, you would move the decimal point _____ places to the _____.

USING SCIENTIFIC NOTATION

The use of scientific notation greatly simplifies multiplication, division, addition and subtraction, since you do not have to keep track of zeros or a number of decimal places. Thus, electrical and electronic problem solving is greatly simplified.

Problems Involving Multiplication

Many problems require the multiplication of quantities. For example, when you use the formula $E = IR$, you multiply the current by the resistance. Assume a certain circuit has a resistance of 300 ohms and carries a current of 20 amperes. To determine the circuit voltage, multiply the resistance by the current as shown below:

$$E = 20 \text{ amperes} \times 300 \text{ ohms} = 6000 \text{ volts.}$$

To solve this problem using regular numbers, you must keep track of a number of zeros. This is avoided by using scientific notation. To work this problem using scientific notation, first convert the values of current and resistance into scientific notation:

$$20 \text{ amperes} = 2 \times 10^1 \text{ amperes}$$

$$300 \text{ ohms} = 3 \times 10^2 \text{ ohms.}$$

Now you have two numbers less than 10 to multiply together (2 and 3). After you multiply the two numbers together, just add the exponents of 10 in both numbers to obtain the exponent of 10 for the answer:

$$E = 2 \times 10^1 \text{ amperes} \times 3 \times 10^2 \text{ ohms} = 6 \times 10^3 \text{ volts.}$$

To check the answer, convert it back to a regular number by moving the decimal point to the right:

$$6 \times 10^3 \text{ volts} = \underset{\curvearrowright}{6.000} \times 10^3 = 6000 \text{ volts.}$$

As another example, suppose a 15,000-ohm resistor carries a current of .005 ampere. Ohm's Law, $E = IR$, can be used to determine the voltage developed across this resistor.

If you multiply the values of current and resistance as they are given, you must keep track of a number of zeros and decimal places. To simplify the

problem, first convert the values of current and resistance into scientific notation:

$$15,000 \text{ ohms} = 1.5 \times 10^4 \text{ ohms}$$

$$.005 \text{ ampere} = 5 \times 10^{-3} \text{ amperes.}$$

To solve the problem, you first multiply 1.5 by 5. Then to obtain the exponent of 10 for your answer, add the exponents of 10 in each number. Since both exponents do not have the same sign, you add them by subtracting the smaller from the larger. The sign of the result is the sign of the larger. In this case subtract 3 from 4 to obtain 1 as the exponent of 10 in the answer:

$$\begin{aligned} E &= IR \\ &= 5 \times 10^{-3} \text{ amperes} \times 1.5 \times 10^4 \text{ ohms} \\ &= 7.5 \times 10^1 \text{ volts or } 75 \text{ volts.} \end{aligned}$$

In summary, to multiply numbers expressed in scientific notation, **MULTIPLY THE NUMBERS TOGETHER AND ADD THE EXPONENTS.** (If the exponents do not have the same sign, subtract the smaller from the larger and use the sign of the larger.)

Problems Involving Division

Scientific notation can also be used in problems where numbers must be divided. Typical problems are those in which current ($I = E/R$) and resistance ($R = E/I$) must be determined.

To show the process of dividing numbers expressed in scientific notation, let's find the current through a 5000-ohm resistor which has 30 volts across it. To solve this problem, use the form of Ohm's Law, $I = E/R$. Using conventional numbers, you can solve the problem as shown below:

$$I = E \div R = 30 \text{ volts} \div 5000 \text{ ohms} = .006 \text{ ampere.}$$

This problem requires that you keep track of zeros and decimal places. To simplify the problem, convert the value of resistance into scientific notation:

$$5000 \text{ ohms} = 5 \times 10^3 \text{ ohms.}$$

To divide the numbers, first write them as a fraction with the number you are dividing (dividend) on the top and the number you are dividing by (divisor) on the bottom:

$$I = \frac{E}{R} = \frac{30 \text{ volts}}{5 \times 10^3 \text{ ohms}}$$

Divide the top number by the bottom number as you normally would. In this case divide 30 by 5 to obtain 6. Next, move the 10 and its exponent from the bottom number up to the top and change its sign. (If it is positive, make it negative and vice versa.) In this example the exponent is positive (10^3), so you make it negative when you move it up on top (10^{-3}):

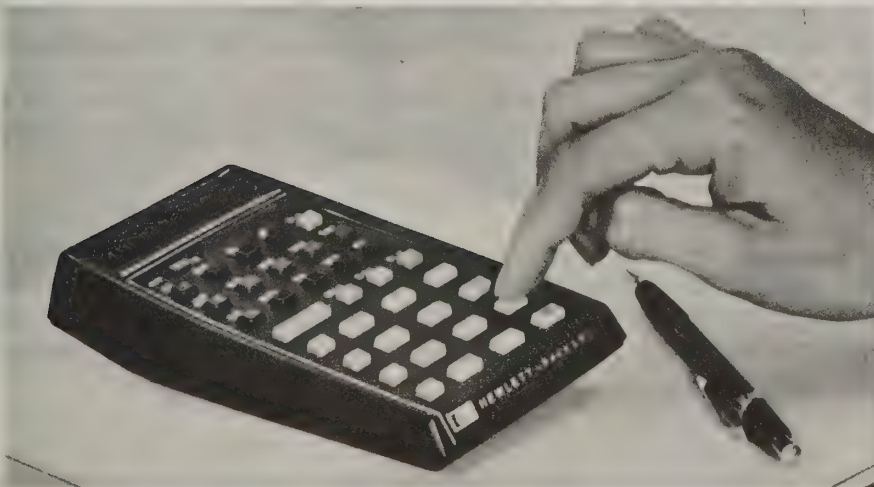
$$I = \frac{30 \times 10^{-3}}{5 \times 10^3} = 6 \times 10^{-3} \text{ amperes.}$$

To check this answer with the one previously obtained (.006), convert 6×10^{-3} to a conventional number (move the decimal point three places to the left since the exponent is -3):

$$6 \times 10^{-3} \text{ amperes} = .006 \times 10^0 \text{ ampere} = .006 \text{ ampere.}$$

Note that this answer is identical to the one previously obtained. Yet you did not have to keep track of zeros or decimal places.

You could have converted 30 into 3×10^1 in working this problem. However, if you did, you would have to divide 3 by 5. This would produce a decimal answer of less than 1. The problem becomes much simpler if you arrange the numbers so that you are dividing a larger number by a smaller number.



Modern "mini" calculators help in electronic problem-solving.

Courtesy Hewlett Packard

ELECTRICAL PROBLEM SOLVING

As another example, suppose a circuit is connected to a 400-volt supply. If the circuit draws a current of .008 ampere, what is its resistance? To solve this problem the simple way, we use powers of ten and the equation $R = E/I$. The first step is to get rid of the decimal places and zeros. In converting the numbers to powers of ten, keep in mind that you will be dividing the 400 by the .008, and the calculation will be simpler if you divide a larger number by a smaller number. Therefore, instead of converting 400 to 4×10^2 , as you might ordinarily do, convert it to 40×10^1 :

$$400 \text{ volts} = 40 \times 10^1 \text{ volts}$$

$$.008 \text{ ampere} = 8 \times 10^{-3} \text{ amperes.}$$

Then write the numbers as a fraction as in $R = E/I$ and divide. Remember, bring the bottom 10 and its exponent up above the line and change the sign of the exponent. Then add the exponents:

$$R = E/I$$

$$= \frac{40 \times 10^1 \text{ volts}}{8 \times 10^{-3} \text{ amperes}}$$

$$= \frac{40 \times 10^1 \times 10^3}{8 \times 10^{-3}} = 5 \times 10^4 \text{ ohms.}$$

In this case the exponent of the bottom number is negative, so you change it to positive when you move it above the line. Then, add the two exponents and convert the answer to a regular number by moving the decimal point four places to the right:

$$R = 5 \times 10^4 \text{ ohms or } 50,000 \text{ ohms.}$$

In summary, to divide numbers expressed in scientific notation: **WRITE THE NUMBERS AS A FRACTION AND DIVIDE THEM AS YOU NORMALLY WOULD. THEN CHANGE THE SIGN OF THE EXPONENT ON THE BOTTOM AND ADD IT TO THE EXPONENT ON THE TOP.**

After you change the sign of the exponent below the line and move it above the line, you may find that the new sign of this exponent is opposite that of the exponent you want to add it to. In this case you just subtract the smaller

from the larger and use the sign of the larger. For example, assume you have a 10^2 above the line, and a 10^3 below the line. When you move the 10^3 above the line, you change it to a 10^{-3} , so you must now add 10^2 to 10^{-3} . The result is 10^{-1} .

Addition and Subtraction

Numbers expressed in scientific notation can also be added and subtracted. However, the numbers you add or subtract must all have the same exponent of 10. If they do not, change the numbers so that they do. Then add or subtract as you normally would.

For the process of addition, assume the solving of an electrical problem requires the addition of 500, 18,000 and 2500. First convert each number to scientific notation:

$$500 = 5 \times 10^2$$

$$18,000 = 1.8 \times 10^4$$

$$2500 = 2.5 \times 10^3$$

Since all three numbers do not have the same exponent, two of them must be changed. It does not make any difference which ones you change. Let's change 5×10^2 and 1.8×10^4 each to a number times 10^3 . In the case of 5×10^2 , the exponent must be increased and thus the decimal must be moved to the left:

$$5 \times 10^2 = \underline{.5} \times 10^3 = .5 \times 10^3.$$

In the case of 1.8×10^4 , the exponent must be decreased and thus the decimal point must be moved to the right:

$$1.8 \times 10^4 = \underline{18.} \times 10^3 = 18 \times 10^3.$$

Now that the numbers all have the same exponent, add them together. Just line up the decimal points and add. The exponent of 10 in the answer is the same as it is in the numbers that are added:

$$\begin{array}{r} .5 \times 10^3 \\ 18. \times 10^3 \\ + 2.5 \times 10^3 \\ \hline 21.0 \times 10^3 \text{ or } 21,000. \end{array}$$

ELECTRICAL PROBLEM SOLVING



The digital computer is often employed to solve complex electrical problems.

Courtesy Scientific Data Systems

As another example, add 1.5×10^{-1} , 3.3×10^1 and 9.1×10^2 . Here again the exponents of each number must be made the same. Let's change 1.5×10^{-1} and 9.1×10^2 each to a number times 10^1 . In the case of 1.5×10^{-1} , the exponent must be made positive and thus the decimal point is moved to the left:

$$1.5 \times 10^{-1} = \underbrace{.01.5}_{.015} \times 10^1 = .015 \times 10^1.$$

For 9.1×10^2 the exponent must be decreased and thus the decimal point is moved to the right:

$$9.1 \times 10^2 = \underbrace{9.1}_{91} \times 10^1 = 91 \times 10^1.$$

Now you can add the numbers as follows:

$$\begin{array}{r}
 .015 \times 10^1 \\
 3.3 \times 10^1 \\
 +91. \times 10^1 \\
 \hline
 94.315 \times 10^1 \text{ or } 943.15
 \end{array}$$

The process used for subtraction is just as simple as the one used for addition. If necessary, change one of the numbers so that both the numbers have the same exponent. Then subtract as you normally would. The exponent in the answer is the same as for the quantities being subtracted. As an example, subtract 1500 from 30,000. First change both numbers into scientific notation:

$$1500 = 1.5 \times 10^3$$

$$30,000 = 3 \times 10^4.$$

Since both numbers do not have the same exponent, one of them must be changed. Either one can be changed. Let's change 3×10^4 to a number times 10^3 . To do this, the exponent of 10 must be decreased and thus the decimal point must be moved to the right:

$$3 \times 10^4 = \underline{30.} \times 10^3 = 30 \times 10^3.$$

Now you can subtract the numbers:

$$\begin{array}{r}
 30 \times 10^3 \\
 - 1.5 \times 10^3 \\
 \hline
 28.5 \times 10^3.
 \end{array}$$

As another example, subtract 5×10^{-1} from 2.1×10^1 . Here again, the exponent of one of the numbers must be changed. Let's change 5×10^{-1} to a number times 10^1 . To do this, the decimal point must be moved to the left and the exponent made positive:

$$5 \times 10^{-1} = \underline{.05.} \times 10^1 = .05 \times 10^1.$$

ELECTRICAL PROBLEM SOLVING

Now you can subtract the numbers:

$$\begin{array}{r} 2.1 \times 10^1 \\ - .05 \times 10^1 \\ \hline 2.05 \times 10^1. \end{array}$$

In summary, **THE EXPONENTS OF 10 MUST BE THE SAME WHEN NUMBERS EXPRESSED IN POWERS OF TEN ARE ADDED OR SUBTRACTED.** The numbers are then added or subtracted in a normal fashion.

REARRANGING OHM'S LAW

There are three forms of Ohm's Law:

$$E = IR \qquad I = E/R \qquad R = E/I.$$

Actually, these three forms are all ways of stating the same law. Two forms ($I = E/R$ and $R = E/I$) are obtained from $E = IR$ by rearranging the formula.

The Ohm's Law formula $E = IR$ is an equation. As the name implies, an equation is an expression of equality. That is, in the equation $E = IR$, the voltage E is equal to the product of current I and resistance R . You can perform any arithmetic operation on an equation as long as you do the **SAME** thing to both sides. For example, consider the equation shown below:

$$4 = 4.$$

This equation states that 4 equals 4. Let's multiply both sides of the equation by 2:

$$2 \times 4 = 4 \times 2$$

$$8 = 8.$$

Although this changes the values of both sides of the equation, note that the left side still equals the right side. Take the original equation and divide both sides by 2:

$$4/2 = 4/2$$

$$2 = 2.$$

The following Practice Exercise questions cover the subjects which you have just studied. They are:

USING SCIENTIFIC NOTATION

PROBLEMS INVOLVING MULTIPLICATION

PROBLEMS INVOLVING DIVISION

ADDITION AND SUBTRACTION

13. The use of scientific notation simplifies mathematical problems (multiplication, division, etc.). True or False?
14. When two numbers are multiplied they must have the same powers of ten in order to use scientific notation. True or False?
15. When using scientific notation in a multiplication problem, you multiply the numbers together and _____ the exponents.
16. A circuit contains a 2500-ohm resistor which carries a current of 10 mA. How much voltage is developed across the resistor? (Use scientific notation and Ohm's Law, $E = IR$, to solve this problem.)
17. A circuit has a resistance of 22,000 ohms. If this circuit carries a current of .004 ampere, what is the circuit voltage? (Use scientific notation and Ohm's Law, $E = IR$, to solve this problem.)
18. What is the current through a 5000-ohm resistor that has 200 volts developed across it? (Use powers of ten and Ohm's Law, $I = E/R$, to solve this problem.)

19. If an electric heating unit draws .1 ampere from a 75-volt battery, what is its resistance? (Use scientific notation and Ohm's Law, $R = E/I$.)
20. Is it necessary that all of the exponents of 10 be the same when numbers expressed in scientific notation or powers of ten are added?
21. Using powers of ten, add the following numbers: 4500; 50,000; and 900.
22. Can 3×10^1 be directly subtracted from 9×10^2 without making any changes in the exponents of 10?
23. Subtract 9×10^2 from 1.8×10^3 .

Here again, the values of both sides have been changed, but the left side still equals the right side.

Now let's take the Ohm's Law expression $E = IR$ and divide both sides of the equation by R :

$$E = IR$$

$$\frac{E}{R} = \frac{\cancel{IR}}{\cancel{R}}$$

$$\frac{E}{R} = I.$$

On the right side of the equation, R divided by R equals 1, so the R 's can be dropped. As a result we obtain the form of Ohm's Law $I = E/R$.

By dividing both sides of the Ohm's Law equation $E = IR$ by I , we can obtain another form of Ohm's Law:

$$E = IR$$

$$\frac{E}{I} = \frac{\cancel{IR}}{\cancel{I}}$$

$$\frac{E}{I} = R.$$

On the right side of the equation I divided by I equals 1, so the I 's can be dropped. Thus, another form of Ohm's Law, $R = E/I$, is obtained.

The three forms of Ohm's Law are: $E = IR$, $I = E/R$ and $R = E/I$. To find voltage when you know the current and resistance, you use $E = IR$. If you know the voltage and resistance, and you want to find the current, use $I = E/R$. You use the form $R = E/I$ if you know the voltage and current, and you want to find the resistance.

COMBINING OHM'S LAW AND THE POWER FORMULA

The electric power formula $P = EI$ enables you to find power when voltage and current are known. This formula can be combined with Ohm's Law to enable you to determine power when current and resistance or voltage and resistance are known.

One form of Ohm's Law states that $E = IR$. Since $E = IR$, we can substitute IR for E in the electric power formula as shown below:

$$P = \textcircled{E} I$$

$$P = (IR) I.$$

I multiplied by itself ($I \times I$) equals I^2 . Therefore, the power formula becomes:

$$P = I^2 R.$$

You use this form of the power formula to find the electric power when you know the current and resistance.

Another form of Ohm's Law states that $I = E/R$. Therefore, we can substitute E/R for I in the power formula as shown below:

$$P = E \textcircled{I}$$

$$P = E(E/R).$$

E multiplied by itself ($E \times E$) equals E^2 . Therefore, the power formula becomes:

$$P = E^2/R.$$

In summary, the three forms of the electric power formula are: $P = EI$, $P = I^2 R$ and $P = E^2/R$. To find power when voltage and current are known, you can use the form $P = EI$. To find power when current and resistance are known, you use the form $P = I^2 R$. To find power when voltage and resistance are known, you can use the form $P = E^2/R$.

SOLVING PROBLEMS

Electric and electronic problem solving becomes very simple once you know the basic methods of problem solving. Problem solving consists of a few simple steps. The first step is to determine the quantity that must be found (the “unknown”). Next you should determine what quantities are known. Once you have determined the unknown and known quantities, you must find an expression that relates the known and unknown quantities. For example, assume you know the voltage and current and must find the resistance. You would use the formula $R = E/I$ since it relates the unknown quantity R to the known quantities E and I .

The next step is to replace the symbols for the known quantities with their number values. Finally, you solve the formula for the unknown quantity. Once the problem is solved, check the results. Make sure they seem reasonable. If the problem involves some circuit or experiment, check the results against circuit operation or against the results of the experiment. We all make errors and a few moments spent checking the results will often show up any errors.

Basic Units

The values you use in a formula must be in the **BASIC UNITS** of the formula. For example, in the Ohm's Law formula the basic units are volts for E , amperes for I and ohms for R . Likewise, in the power formula the basic unit for power is the watt. Therefore, you cannot use K ohms, megohms, μA , mA, etc., directly in a formula. They must be converted into basic units. Scientific notation can be used to simplify the conversion into basic units. Since 1 milliamper (1 mA) is equal to .001 ampere, 1 mA can be written as 1×10^{-3} ampere. Thus, when a value of current appears in mA, just multiply this value by 10^{-3} to convert it to amperes. For example, suppose the value of current is given as 35 mA. To convert it to amperes, just drop the mA and multiply 35 by 10^{-3} to obtain 35×10^{-3} amperes. If you prefer, this can also be written as 3.5×10^{-2} amperes.

Values of current expressed as microamperes can be converted into amperes in a similar manner. Since 1 microampere (1 μA) is equal to .000001 ampere, 1 μA can be written as 1×10^{-6} ampere. Thus, when a value of current appears in μA , just multiply this value by 10^{-6} to convert it to amperes. As an example, suppose the value of current in a problem is 15 μA . To convert this value into amperes, multiply it by 10^{-6} to obtain 15×10^{-6} or 1.5×10^{-5} amperes.

Resistance is not always given in basic units. The letter K, which represents 1000, is often used. Since 1 k Ω equals 1000 ohms, 1 k Ω can be written as 1×10^3 ohms. Thus, when a value of resistance is given in K ohms, multiply it by 10^3 before you use it in a formula that calls for resistance in ohms. For example, assume the value of resistance in a circuit is 5 k Ω . To convert this value, multiply by 10^3 to obtain 5×10^3 ohms.

Resistance values are also given in megohms. Since 1 M Ω equals 1,000,000 ohms, 1 M Ω can be written as 1×10^6 ohms. Therefore, when a value of resistance is given in megohms, multiply this value by 10^6 to convert this value into ohms. For example, assume the value of resistance is 4.7 M Ω . To convert this value into ohms, multiply by 10^6 to obtain 4.7×10^6 ohms.

Ohm's Law Problems

Many electric and electronic problems involve the use of one of the forms of Ohm's Law. To show the method of using Ohm's Law, let's solve a typical problem. Assume a certain circuit offers a resistance of 4 k Ω to the supply battery. If this circuit operates from a 28-volt source, how much current does it draw?



Taken in its entirety, an AM/FM stereo receiver is quite complex. However, if it is broken down into basic circuits, it can be analyzed as a combination of series and parallel circuits.

Courtesy H. H. Scott

The unknown quantity in this problem is current, and the known quantities are voltage and resistance. To solve this problem, you would use the Ohm's Law formula $I = E/R$. Before using the values in the formula, determine if they are in their basic units. Since resistance is given in K ohms, it must be converted to ohms by multiplying 10^3 . Thus, 4 k Ω equals 4×10^3 ohms.

The problem can now be solved by replacing the letter symbols in the formula with the values of voltage and resistance:

$$I = \frac{E}{R} = \frac{28 \text{ volts}}{4 \times 10^3 \text{ ohms}}$$

$$= \frac{28 \times 10^{-3}}{4 \times 10^3}$$

$$= 7 \times 10^{-3} \text{ or } .007 \text{ ampere.}$$

Note that the 28 was not converted into scientific notation. It is much easier to divide 28 by 4 than to divide 2.8×10^1 by 4.

As another example, assume you wish to determine the voltage developed across a 22 k Ω resistor that has a current of 5 mA through it. Since resistance and current are known and voltage is unknown, the Ohm's Law formula $E = IR$ is used. Before using the values of resistance and current in the formula, they must be converted to basic units as shown below:

$$22 \text{ k}\Omega = 22 \times 10^3 \text{ ohms or } 2.2 \times 10^4 \text{ ohms}$$

$$5 \text{ mA} = 5 \times 10^{-3} \text{ amperes.}$$

These values of resistance and current can now be used in the formula:

$$E = IR = 5 \times 10^{-3} \text{ amperes} \times 2.2 \times 10^4 \text{ ohms}$$

$$= 11.0 \times 10^1 \text{ or } 110 \text{ volts.}$$

Electric Power Problems

In problems involving electric power, one of the forms of the power formula is often used: $P = EI$, $P = I^2R$ and $P = E^2/R$. To show how the power formula is used, let's solve an example problem. Suppose you wish to find the power dissipated in a circuit if it draws 2.5 amperes from a 5000-volt supply. Since voltage and current are known, you use the formula $P = EI$ to solve this problem. Although the current and voltage are in basic units, the voltage can be simplified by using scientific notation:

$$5000 \text{ volts} = 5 \times 10^3 \text{ volts.}$$

The problem is solved by inserting the values in place of the letter symbols, just as in using Ohm's Law:

$$\begin{aligned} P &= EI \\ &= 5 \times 10^3 \text{ volts} \times 2.5 \text{ amperes} \\ &= 12.5 \times 10^3 \text{ or } 12,500 \text{ watts.} \end{aligned}$$

As another example, suppose you wish to find the power dissipated by a 5 k Ω resistor which is carrying 10 mA of current. Since resistance and current are known, you use the formula $P = I^2R$ to solve this problem. The values of current and resistance must be converted into basic units:

$$\begin{aligned} 10 \text{ mA} &= 10 \times 10^{-3} \text{ or } 1 \times 10^{-2} \text{ ampere} \\ 5 \text{ k}\Omega &= 5 \times 10^3 \text{ ohms.} \end{aligned}$$

The problem is now solved by inserting the values as shown below:

$$P = I^2R = (1 \times 10^{-2} \text{ ampere})^2 \times 5 \times 10^3 \text{ ohms.}$$

Note that the current must be squared. To square a number in scientific notation, just square the number and double the exponent of 10:

$$P = 1 \times 10^{-4} \times 5 \times 10^3 = 5 \times 10^{-1} \text{ or } .5 \text{ watt.}$$

In some electric power problems you may know the power and resistance, and you may want to calculate the current. For example, suppose the power dissipated by a 2000-ohm resistor is 5 watts. To find the current through the resistor, you rearrange the formula $P = I^2R$ to the form:

$$\begin{aligned} I^2 &= \frac{P}{R} \\ I &= \sqrt{\frac{P}{R}} \end{aligned}$$

Inserting the power and resistance values, you get:

$$I = \sqrt{\frac{5}{2000}} = \sqrt{.0025} = \sqrt{25 \times 10^{-4}}$$

To find the square root of a number expressed in scientific notation, you simply take the square root of the number and divide the exponent of 10 by 2. The square root of 25 is 5, and -4 divided by 2 is -2 . Thus, the current through the resistor in this example is 5×10^{-2} ampere or .05 ampere (50 mA).

The exponent of 10 should be an even number. A number such as 2.5×10^{-3} can be put into this form by moving the decimal point one place to the right ($2.5 \times 10^{-3} = 25 \times 10^{-4}$).

The following Practice Exercise questions cover the subjects which you have just studied. They are:

REARRANGING OHM'S LAW

COMBINING OHM'S LAW AND THE POWER FORMULA

SOLVING PROBLEMS

BASIC UNITS

OHM'S LAW PROBLEMS

ELECTRIC POWER PROBLEMS

24. What are the three forms of Ohm's Law?
25. How are the other two forms of Ohm's Law obtained from $E = IR$?
26. What are the three forms of the electric power formula?
27. If current and resistance are given, what formula would you use to determine power?

Convert the following values into basic units using scientific notation.

28. 15 mA

29. 1.9 μA

30. 68 $\text{k}\Omega$

31. $2.2 \text{ M}\Omega$
32. To find current when you know voltage and resistance, what Ohm's Law formula would you use?
33. What is the resistance of a circuit if it draws 2.5 mA from a 9-volt source?
34. If a $470 \text{ k}\Omega$ resistor carries a current of $50 \text{ }\mu\text{A}$, how much voltage appears across the resistor?
35. To find power when you know the voltage and resistance, what electric power formula is used?
36. A $10 \text{ k}\Omega$ resistor in a circuit carries 5 mA . If this resistor has a 10-watt rating, is it dissipating more or less power than its rated wattage?
37. What is the square root of 16×10^6 ?

SUMMARY

Scientific notation can be used to simplify numbers with many zeros or decimal places. Like anything new, this method of handling numbers requires practice. However, once you learn to use it correctly, you can easily handle very large or very small numbers. It is truly a short cut worth mastering.

Arithmetic operations can be performed with numbers expressed in scientific notation. When adding or subtracting, make sure that the exponents of the numbers are the same, and then add or subtract the numbers. To multiply numbers, multiply as you normally would, and then add the exponents. For division, divide as you normally would, and then change the sign of the exponent in the divisor and add the exponents.

Ohm's Law and the electric power formulas are often used to solve electric and electronic problems. Depending on which quantities are known and unknown, one of the three forms of Ohm's Law can be used: $E = IR$, $I = E/R$ or $R = E/I$. Depending on the known and unknown quantities, one of the three power formulas can be used: $P = EI$, $P = I^2R$ or $P = E^2/R$.

The quantities substituted into the Ohm's Law or electric power formulas must be in basic units: volts for E , amperes for I , ohms for R and watts for P .

IMPORTANT DEFINITIONS

BASIC UNITS — The fundamental values of an equation. For electric power the basic units are: watts (P), volts (V) and amperes (I). If any of these terms are in any other form (kW—kilowatt, mV—millivolt, μ A—micro-ampere, etc.) they must be converted to the basic unit in order to obtain correct and meaningful answers. For example, 1 kW = 1,000 watts; 1 mV = .001 volt; and 1 μ A = .000001 ampere.

EXPONENT—A number placed to the right and slightly above another number. For example, in the number 10^2 , the 2 is the exponent of the number 10. The exponent indicates how many times a number is to be multiplied by itself ($10^2 = 10 \times 10 = 100$, $4^3 = 4 \times 4 \times 4 = 64$, $2^4 = 2 \times 2 \times 2 \times 2 = 16$, etc).

POWER OF TEN—An exponent of the number 10. For 10^2 the power of ten is 2, or 10 multiplied by itself two times.

SCIENTIFIC NOTATION—The use of the exponents of the number 10 ($10^0 = 1$, $10^1 = 10$, $10^2 = 100$, $10^3 = 1000$, etc.). In scientific notation we will have a number between 1.000 and 9.999 times a power of 10. For example, the number 123 will become 1.23×10^2 in scientific notation.

PRACTICE EXERCISE SOLUTIONS

1. exponent
2. ten
3. power of 10
4. (a) $100^0 = 1$; (b) $10^7 = 10,000,000$; (c) $5^3 = 125$.
5. (a) $100 = 10^2$; (b) $25 = 5^2$; (c) $1 = 756^0$.
6. (a) $1000 = 1 \times 10^3$; (b) $400 = 4 \times 10^2$; (c) $700,000 = 7 \times 10^5$.
7. (a) $57,000 = 5.7000. \times 10^4 = 5.7 \times 10^4$; (b) $4,700 = 4.700. \times 10^3 = 4.7 \times 10^3$; (c) $9,375 = 9.375. \times 10^3 = 9.375 \times 10^3$; (d) $386.5 = 3.86.5 \times 10^2 = 3.865 \times 10^2$.
8. (a) $7.6 \times 10^3 = 7.600. = 7,600$; (b) $6.58 \times 10^1 = 6.5.8 = 65.8$; (c) $9.5755 \times 10^5 = 9.57550. = 957,550$.
9. (a) $.005 = .005. \times 10^{-3} = 5 \times 10^{-3}$; (b) $.0755 = .07.55 \times 10^{-2} = 7.55 \times 10^{-2}$; (c) $.00000073 = .0000007.3 \times 10^{-7} = 7.3 \times 10^{-7}$.
10. (a) $5.5 \times 10^{-3} = .005.5 = .0055$; (b) $6 \times 10^{-8} = .00000006. = .00000006$; (c) $3.75 \times 10^{-1} = .3.75 = .375$.
11. four; left
12. three; right
13. True
14. False—To multiply you add the powers of ten.
15. add
16. 2.5×10^1 or 25 volts.—Converting current and resistance values into scientific notation yields: $10 \text{ mA} = 1 \times 10^{-2}$ amperes and $2500 \text{ ohms} = 2.5 \times 10^3 \text{ ohms}$. The voltage across the resistor is therefore:

$$E = IR = 1 \times 10^{-2} \text{ amperes} \times 2.5 \times 10^3 \text{ ohms} = 2.5 \times 10^1$$

or 25 volts.

PRACTICE EXERCISE SOLUTIONS (Continued)

17. 8.8×10^1 or 88 volts.—Converting current and resistance into scientific notation yields: .004 ampere = 4×10^{-3} amperes and 22,000 ohms = 2.2×10^4 ohms. The circuit voltage is then equal to:

$$\begin{aligned} E &= IR = 4 \times 10^{-3} \text{ amperes} \times 2.2 \times 10^4 \text{ ohms} \\ &= 8.8 \times 10^1 \text{ or } 88 \text{ volts.} \end{aligned}$$

18. 4×10^{-2} or .04 ampere.—Converting voltage and resistance into powers of ten yields: 200 volts = 20×10^1 volts and 5000 ohms = 5×10^3 ohms. The current is then equal to:

$$\begin{aligned} I &= \frac{E}{R} = \frac{20 \times 10^1}{5 \times 10^3} = \frac{20 \times 10^1 \times 10^{-3}}{5 \times 10^3} \\ &= 4 \times 10^{-2} \text{ or } .04 \text{ ampere.} \end{aligned}$$

19. 7.5×10^2 or 750 ohms.—Converting voltage and current into scientific notation yields: 75 volts = 7.5×10^1 volts and .1 ampere = 1×10^{-1} ampere. The resistance is then:

$$\begin{aligned} R &= \frac{E}{I} = \frac{7.5 \times 10^1}{1 \times 10^{-1}} = \frac{7.5 \times 10^1 \times 10^1}{1 \times 10^{-1}} \\ &= 7.5 \times 10^2 \text{ or } 750 \text{ ohms.} \end{aligned}$$

20. Yes

21. 55.4×10^3 or 55,400.—Changing each number into powers of ten with the number 3 as the exponent of 10 yields:

4500 = 4.5×10^3 ; 50,000 = 50×10^3 ; and 900 = $.9 \times 10^3$. The numbers are then added.

$$\begin{array}{r} 4.5 \times 10^3 \\ 50 \times 10^3 \\ .9 \times 10^3 \\ \hline 55.4 \times 10^3 \text{ or } 55,400. \end{array}$$

22. No.—Both numbers must have the same exponent of 10 before they can be subtracted.

23. $.9 \times 10^3$ or 900.—Changing 9×10^2 to a number times 10^3 yields:

$9 \times 10^2 = .9 \times 10^3$. The subtraction can then be performed:

$$\begin{array}{r} 1.8 \times 10^3 \\ - .9 \times 10^3 \\ \hline .9 \times 10^3 \text{ or } 900. \end{array}$$

PRACTICE EXERCISE SOLUTIONS (Continued)

24. $E = IR$; $I = E/R$; and $R = E/I$.

25. The other forms are obtained by rearranging $E = IR$. The form $I = E/R$ is obtained by dividing both sides of $E = IR$ by R , and $R = E/I$ is obtained by dividing both sides of $E = IR$ by I :

$$E = IR$$

Dividing by R

$$\frac{E}{R} = \frac{IR}{R}$$

which equals $\frac{E}{R} = I$

or

$$I = \frac{E}{R}$$

Dividing by I

$$\frac{E}{I} = \frac{IR}{I}$$

which equals $\frac{E}{I} = R$

or

$$R = \frac{E}{I}$$

26. $P = EI$; $P = I^2R$; and $P = E^2/R$.

27. $P = I^2R$.

28. 15×10^{-3} or 1.5×10^{-2} amperes.

29. 1.9×10^{-6} amperes.

30. 68×10^3 or 6.8×10^4 ohms.

31. 2.2×10^6 ohms.

32. $I = E/R$.

33. 3600 or 3.6 k Ω .—To solve the problem, you would use the Ohm's Law formula, $R = E/I$. Since current is given in mA, it must first be converted to amperes: $2.5 \text{ mA} = 2.5 \times 10^{-3}$ amperes. The problem is then solved as follows:

$$\begin{aligned} R &= \frac{E}{I} = \frac{9 \text{ volts}}{2.5 \times 10^{-3} \text{ amperes}} \\ &= \frac{9 \times 10^3}{2.5 \times 10^{-3}} = 3.6 \times 10^3 \text{ or } 3600 \text{ ohms.} \end{aligned}$$

PRACTICE EXERCISE SOLUTIONS (Continued)

34. 23.5 volts.—To solve this problem, you would use the Ohm's Law formula, $E = IR$. Current and resistance must be converted to basic units: $470 \text{ k}\Omega = 470 \times 10^3 \text{ ohms} = 4.7 \times 10^5 \text{ ohms}$, and $50 \text{ }\mu\text{A} = 50 \times 10^{-6} \text{ amperes} = 5 \times 10^{-5} \text{ amperes}$. The problem is then solved as shown below:

$$\begin{aligned} E &= IR = 5 \times 10^{-5} \text{ amperes} \times 4.7 \times 10^5 \text{ ohms} \\ &= 23.5 \times 10^0 \text{ or } 23.5 \text{ volts.} \end{aligned}$$

35. $P = E^2/R$.

36. less—To solve this problem, you use the formula $P = I^2R$. Since the values of current and resistance are not in basic units, they must be converted: $5 \text{ mA} = 5 \times 10^{-3} \text{ amperes}$, and $10 \text{ k}\Omega = 10 \times 10^3 \text{ or } 1 \times 10^4 \text{ ohms}$. The power dissipated is then found as shown below:

$$\begin{aligned} P &= I^2R = (5 \times 10^{-3} \text{ amperes})^2 \times 1 \times 10^4 \text{ ohms} \\ &= 25 \times 10^{-6} \times 1 \times 10^4 \\ &= 25 \times 10^{-2} \text{ or } .25 \text{ watt.} \end{aligned}$$

Since the resistor is a 10-watt resistor, it is dissipating much less than its rated power.

37. 4×10^3 .—The square root of 16 is 4, and the square root of 10^6 is 10^3 .

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

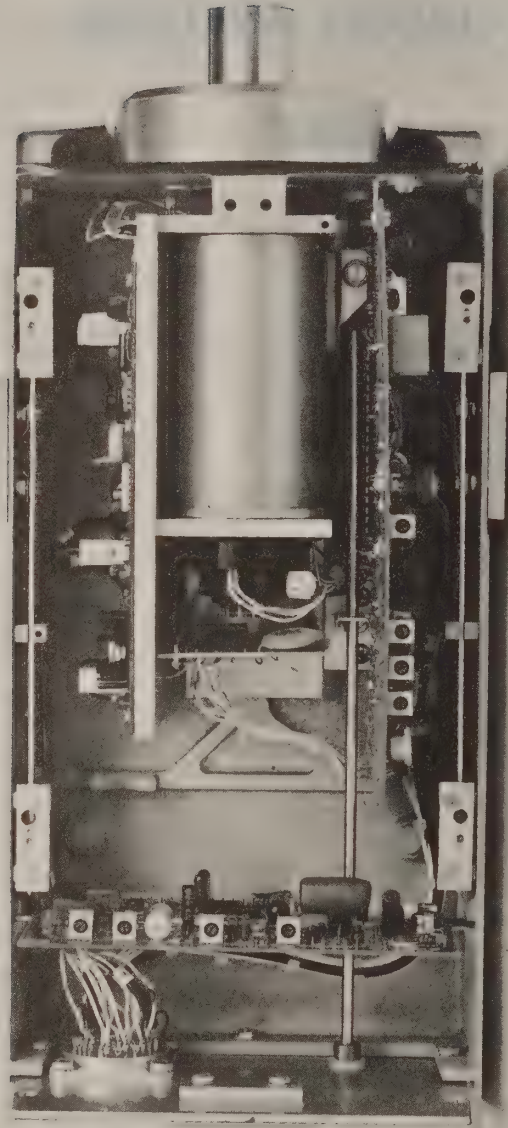
LESSON CODE
1019A

Example: An apple is a
 A ☐ B ☐ C ☒ D ☐
 A. meat. B. vegetable. C. fruit. D. soup.

1. A ☐ B ☐ C ☐ D ☐ In the number 5.5×10^2 , the 2 above and to the right of the 10 is called the
 (A) exponent. (B) divisor. (C) difference. (D) sum.
2. A ☐ B ☐ C ☐ D ☐ 47,000 ohms expressed in scientific notation is
 (A) 4.7×10^{-4} ohms. (B) 470×10^3 ohms. (C) 4.7×10^4 ohms. (D) 470×10^{-3} ohms.
3. A ☐ B ☐ C ☐ D ☐ In scientific notation, .0022 ampere equals
 (A) 2.2×10^{-3} amperes. (B) 2.2×10^3 amperes. (C) 22×10^{-3} amperes. (D) .22 $\times 10^{-1}$ ampere.
4. A ☐ B ☐ C ☐ D ☐ The number 3.7×10^4 equals
 (A) 370. (B) 370,000. (C) 37,000. (D) 37.
5. A ☐ B ☐ C ☐ D ☐ What voltage is developed across a 5×10^3 ohm resistor that is carrying 4×10^{-2} amperes?
 (A) 20,000,000 volts. (B) 4×10^{-1} volts. (C) 2×10^2 volts. (D) 8×10^{-2} volts.
6. A ☐ B ☐ C ☐ D ☐ If a circuit has a resistance of 5000 ohms and is connected to a 75-volt battery, how much current flows?
 (A) 15×10^1 amperes. (B) 1.5×10^{-2} amperes. (C) 9×10^{-3} amperes. (D) 25×10^{-1} amperes.
7. A ☐ B ☐ C ☐ D ☐ If voltage and current are known and resistance must be found, the formula to use is
 (A) $E = P/I$. (B) $I = \sqrt{P/R}$. (C) $P = I^2R$. (D) $R = E/I$.
8. A ☐ B ☐ C ☐ D ☐ If current and resistance are known and power must be found, the formula to use is
 (A) $E = P/I$. (B) $R = E/I$. (C) $E = IR$. (D) $P = I^2R$.
9. A ☐ B ☐ C ☐ D ☐ Converting 9.7 mA into basic units with scientific notation produces
 (A) 9.7×10^{-3} amperes. (B) 9.7×10^{-2} amperes. (C) 9.7×10^6 amperes. (D) 9.7×10^{-6} amperes.
10. A ☐ B ☐ C ☐ D ☐ How much power does a 5K ohm resistor dissipate if it carries 9 mA?
 (A) 4,050 watts. (B) .593 watt. (C) 593 watts. (D) .405 watt.

DC CIRCUIT ANALYSIS

1022



Although circuits in this TV camera may appear quite complex, they can be broken down into combinations of series and parallel circuits.

Courtesy Cohu Electronics, Inc.

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If yesterday was a dismal failure, then turn those failings into success today. Josh Billings once said "It ain't no disgrace to make a mistake. The disgrace comes in making the same mistake twice."

—Selected

DC CIRCUIT ANALYSIS

The most involved electronic equipment is made up of simple series and parallel circuits in different combinations. The ability to work with simple dc circuits opens the door to understanding and working with thousands of more complicated circuits. The methods explained in this lesson apply to the largest power control circuits, as well as the smallest transistorized circuits.

DC CIRCUITS

There are two basic types of dc circuits: the series circuit and the parallel circuit. Ohm's Law can be used to determine voltage, current and resistance in either type of circuit. Most electrical and electronic equipment does not consist of just one or the other circuit type. Instead, most equipment consists of a combination of series and parallel circuits. This arrangement is usually referred to as a **COMBINATION CIRCUIT**.

When properly analyzed, combination circuits can be as easy to work with as simple series or parallel circuits. The series and parallel sections making up a combination circuit may be handled separately. Thus, an elaborate combination circuit can be broken down into simple elements which can be analyzed through Ohm's Law.

SERIES CIRCUITS

Remember that a series circuit has one and only one path for current. Because of this single path, the same current flows through each component. The components which make up a series circuit, or any circuit, need not be just resistors. Transistors, vacuum tubes, heating elements and other types of components can make up a series circuit. These components are often treated as resistances since they all oppose the flow of electrons.



Figure
1

Figure 1 shows an example of a series circuit. This is the filament circuit of a vacuum tube amplifier. The filaments, which are inside the vacuum tubes, heat the tubes to the proper operating temperature. Because of the series connection of the filaments and R_1 , the same current flows through all the components of the circuit. If a series circuit is broken at any point, no current will flow. For example, assume one of the tube filaments shown

in Figure 1 burns out. This opens the circuit, stopping current from flowing through any of the other tube filaments.

Determining Resistance in Series Circuits

The total resistance of a series circuit is equal to the sum of the individual resistances included in the circuit. For example, let's find the total resistance of the circuit shown in Figure 2. To determine the total resistance of this circuit, all you have to do is add the values of the individual resistances. Note that the resistances in Figure 2 are given in $k\Omega$ ($1 k\Omega = 1000 \text{ ohms}$). Sometimes the ohm sign, Ω , is dropped. However, remember that no matter which way it is shown— $10K$, $10K \text{ ohms}$ or $10 k\Omega$ —they all mean 10,000 ohms.

To find the total resistance, you could convert the values into ohms before adding them. However, since the resistances are all in $k\Omega$, you can add them directly. This "short cut" can be used whenever all the resistances are expressed in the same manner: all in ohms, all in $k\Omega$ (1000 ohms) or all in $M\Omega$ (1,000,000 ohms):

$$R_T = 10 k\Omega + 150 k\Omega + 5 k\Omega = 165 k\Omega \text{ or } 165,000 \text{ ohms}$$

or

$$R_T = 10,000 + 150,000 + 5,000 = 165,000 \text{ ohms.}$$

In some cases the values of the individual resistances may not be known. However, if the circuit current and the voltages across the individual resistances are known, individual resistance values as well as the total resistance can be found by using Ohm's Law.

Suppose you wish to find the resistances of the filaments in Figure 3. As shown, the circuit current is 150 mA. Since this is a series circuit, the same current flows through each component. Ohm's Law ($R=E/I$) states that resistance is equal to the voltage in volts divided by the current in amperes. Therefore, the resistance of each filament is equal to the voltage across the filament divided by the circuit current.

Let's find the resistance of one of the 12-volt filaments by dividing the filament voltage, 12 volts, by the filament current, which is 150 mA or .15 ampere. For convenience, we can express the current value as 1.5×10^{-1} ampere:

$$R = \frac{12}{1.5 \times 10^{-1}} = \frac{12 \times 10^1}{1.5} = 8 \times 10^1 = 80 \text{ ohms.}$$

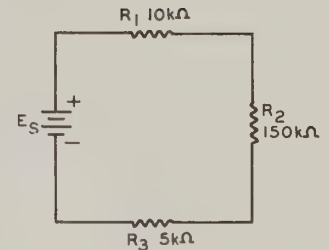


Figure
2

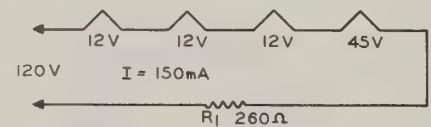


Figure
3

Since the same current flows through the other two 12-volt filaments and produces the same voltage across each, they also have resistances of 80 ohms. You would find the resistance of the 45-volt filament shown in Figure 3 similarly. The current through this filament is also 1.5×10^{-1} ampere:

$$R = \frac{45}{1.5 \times 10^{-1}} = \frac{45 \times 10^1}{1.5}$$

$$= 30 \times 10^1 \text{ or } 300 \text{ ohms.}$$

The total resistance of the circuit can now be found by adding the resistances of the filaments and R_1 :

$$R_T = 80 + 80 + 80 + 300 + 260 = 800 \text{ ohms.}$$

The filament circuit offers a resistance of 800 ohms to the 120-volt supply.

The total resistance of a series circuit can also be found by using Ohm's Law without adding the individual resistances. To do this, you simply divide the supply voltage by the total circuit current. Remember, resistance always equals voltage divided by current ($R = E/I$).

The circuit of Figure 3 is connected to a 120-volt (1.2×10^2 volts) supply and the circuit current is 150 mA (1.5×10^{-1} ampere). To find the total circuit resistance, divide 1.2×10^2 by 1.5×10^{-1} :

$$R_T = \frac{1.2 \times 10^2}{1.5 \times 10^{-1}} = \frac{1.2 \times 10^3}{1.5}$$

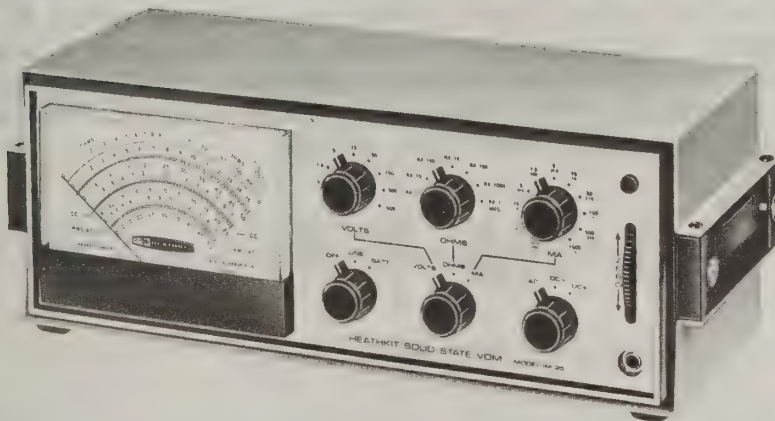
$$= .8 \times 10^3 \text{ or } 800 \text{ ohms.}$$

Note that this is exactly the same total resistance we obtained by adding the circuit resistances. In summary, **THE TOTAL RESISTANCE OF A SERIES CIRCUIT IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES AND IS ALSO EQUAL TO THE SUPPLY VOLTAGE DIVIDED BY THE CIRCUIT CURRENT.** The Ohm's Law formula, $R = E/I$, can also be used to determine the resistances if the circuit current and the voltages across the components are known.

Current and Voltage in Series Circuits

Remember that the current is the same in all parts of a series circuit. The circuit current depends on the total circuit resistance and the source or supply voltage. The circuit current, by Ohm's Law, is equal to the source voltage divided by the total circuit resistance ($I=E/R$). If the **TOTAL RESISTANCE INCREASES** and the supply voltage remains the same, **CIRCUIT CURRENT DECREASES**. If the **TOTAL RESISTANCE DECREASES** and the supply voltage remains the same, **CIRCUIT CURRENT INCREASES**. Thus, the current variation is just opposite the resistance variation.

Conversely, if circuit resistance remains constant and the supply voltage is varied, the circuit current varies in proportion to the voltage. If the **SUPPLY VOLTAGE INCREASES** and circuit resistance remains constant, the **CIRCUIT CURRENT INCREASES**, and vice versa.



Voltage, current and resistance in series and parallel circuits can be measured with this transistorized VOM.

Courtesy Heath Co.

Figure 4 shows a simple circuit which provides speed control for a dc motor. Notice that the variable resistance, R_1 , is connected in series with the dc motor. The total circuit resistance as well as the circuit current depends on the resistances of R_1 and the motor. As the slider of R_1 is moved toward point A, the resistance of R_1 decreases, thus decreasing the total circuit resistance. In turn, the circuit current increases, and this causes a corresponding increase in motor speed. If the slider of R_1 is moved toward point B, the resistance of R_1 increases, thus increasing the total circuit resistance. In turn, the circuit current decreases, decreasing the motor speed.

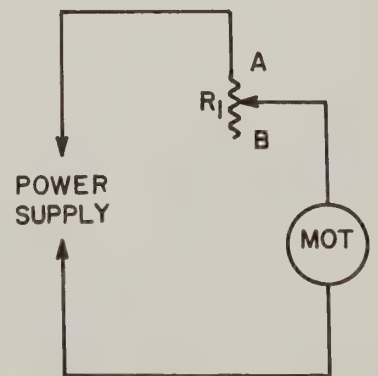


Figure 4

Thus, control of circuit resistance is used to control the motor speed in Figure 4. Many dc motor-control systems in use today employ the basic principle of Figure 4. These systems use semiconductor devices which act as variable resistances.

To determine the current flowing through a series circuit, we use Ohm's Law, $I = E/R$. For example, assume that the dc motor shown in Figure 4 has a resistance of 50 ohms. If R_1 is set so that the resistance it presents to the circuit is 10 ohms, the total circuit resistance is $50 + 10$, or 60 ohms. Also assume that the supply voltage is 240 volts. To find the circuit current, simply divide the supply voltage by the total resistance:

$$I = \frac{E}{R} = \frac{240}{60} = 4 \text{ amperes.}$$

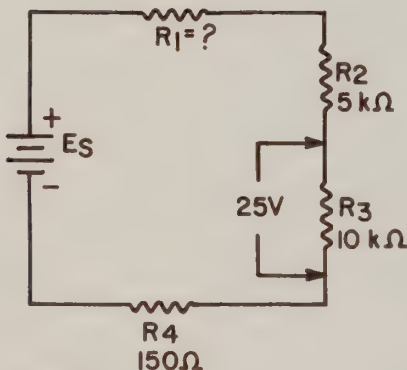


Figure 5

The current in a series circuit can also be found without knowing the total circuit resistance or the supply voltage. Assume you wish to determine the current in the circuit of Figure 5. Notice that the supply voltage, E_s , and the resistance of R_1 are not given. However, the voltage across R_3 is given. Since the current is the same through all parts of a series circuit, you can calculate circuit current by determining the current through R_3 . The current through R_3 is found by Ohm's Law, $I = E/R$:

$$I = \frac{25}{10K} = \frac{2.5 \times 10^1}{1 \times 10^4} = \frac{2.5 \times 10^1 \times 10^{-4}}{1} = \frac{2.5 \times 10^{-3}}{1} \\ = 2.5 \times 10^{-3} \text{ or } .0025 \text{ ampere (2.5 mA).}$$

The current through R_3 , as well as the total circuit current, is equal to 2.5 mA or .0025 ampere. If the voltage appearing across R_2 or R_4 were known, the circuit current could be found by determining the current through these resistors. In summary, **THE CURRENT FLOWING THROUGH A SERIES CIRCUIT IS EQUAL TO THE SUPPLY VOLTAGE DIVIDED BY THE TOTAL CIRCUIT RESISTANCE, $I = E/R$.** The circuit current can also be found by dividing the voltage across any one of the components in the circuit by its resistance.

The voltages across the various components in a series circuit can be found by using Ohm's Law, $E = IR$. All you need to do is multiply the current through the component by the resistance of the component. As an example, let's determine the voltages across the three resistors in the series circuit shown in Figure 6. The first step is to determine the total circuit resistance

so that the circuit current can be found. The total resistance is the sum of the individual resistances, and the circuit current is equal to the source voltage divided by the total circuit resistance:

$$R_T = 50 \text{ k}\Omega + 15 \text{ k}\Omega + 135 \text{ k}\Omega = 200 \text{ k}\Omega \text{ or } 200,000 \text{ ohms.}$$

$$I = \frac{100}{200\text{K}} = \frac{1.0 \times 10^2}{2 \times 10^5} = \frac{1 \times 10^2 \times 10^{-5}}{2}$$

$$= .5 \times 10^{-3} = .0005 \text{ ampere (.5 mA).}$$

Since the same current flows through all components in a series circuit, the voltage across each resistor shown in Figure 6 can be found by multiplying its resistance by .0005 ampere, $E=IR$:

$$E_{R_1} = 50\text{K} \times .0005 = 5 \times 10^4 \times 5 \times 10^{-4}$$

$$= 25 \times 10^0 = 25 \text{ volts.}$$

$$E_{R_2} = 15\text{K} \times .0005 = 1.5 \times 10^4 \times 5 \times 10^{-4}$$

$$= 7.5 \times 10^0 = 7.5 \text{ volts.}$$

$$E_{R_3} = 135\text{K} \times .0005 = 13.5 \times 10^4 \times 5 \times 10^{-4}$$

$$= 67.5 \times 10^0 = 67.5 \text{ volts.}$$

The voltage across R_1 is 25 volts, the voltage across R_2 is 7.5 volts, and the voltage across R_3 is 67.5 volts. An important point to remember is that the voltages across the resistors depend on the resistance values. The 135 k Ω resistor shown in Figure 6 has the greatest voltage drop, while the 15 k Ω resistor has the least. Therefore, the largest resistance in a series circuit has the largest voltage drop, and the smallest resistance has the smallest voltage drop. The term "voltage drop" is used to describe the voltage appearing across a component in a circuit.

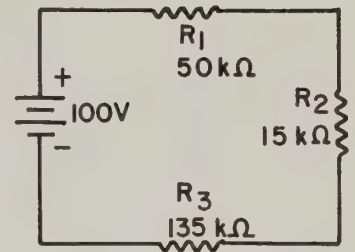


Figure
6

Kirchhoff's Voltage Law

Let's examine the voltage relationship shown in Figure 6 in greater detail. In this circuit the supply voltage is 100 volts. The voltages developed across

the various resistors, as found earlier, are: $E_{R_1}=25$ volts, $E_{R_2}=7.5$ volts and $E_{R_3}=67.5$ volts. If you add the voltage drops across the resistors, you will find that they equal the supply voltage of 100 volts:

$$E_{R_1} + E_{R_2} + E_{R_3} = 25 + 7.5 + 67.5 = 100 \text{ volts.}$$

The relationship, known as **KIRCHHOFF'S VOLTAGE LAW**, states that the sum of the voltage drops appearing across the components in a series circuit equals the source voltage.

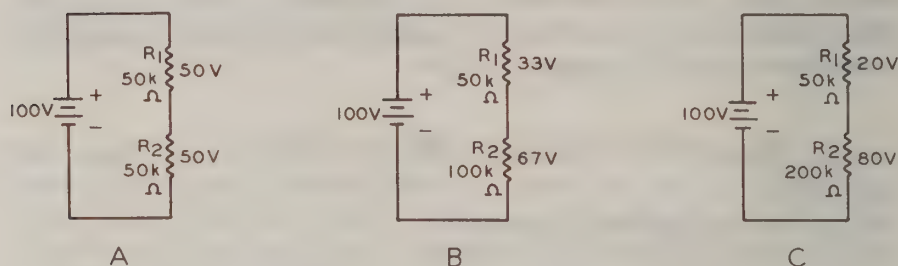


Figure 7

Figure 7 shows the voltage relationships in a series circuit in greater detail. In Figure 7A, R_1 and R_2 have the same value. As a result, the voltage drop across each resistor is the same. Note that the sum of the voltage drops equals the supply voltage. In Figure 7B, R_2 is twice the value of R_1 and thus the voltage drop across R_2 is twice as large as the voltage drop across R_1 . However, the sum of the voltage drops still equals the source voltage. The value of R_2 in Figure 7C is four times the value of R_1 , and thus the voltage drop across R_2 is four times as large as the voltage drop across R_1 . Again, the sum of the voltage drops equals the supply voltage.

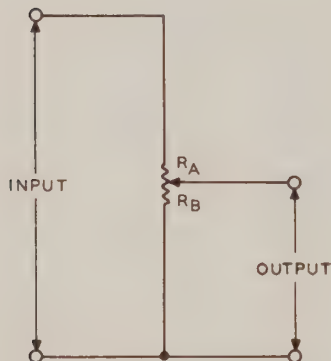


Figure 8

In summary, we can state: **THE SUM OF THE VOLTAGE DROPS IN A SERIES CIRCUIT EQUALS THE SUPPLY VOLTAGE** (Kirchhoff's voltage law). The individual voltage drops depend on the resistance values of the components.

Figure 8 shows how a potentiometer is a practical application of the voltage vs. resistance relationship in a series circuit. A potentiometer can be analyzed as having two separate resistances—the resistance from the slider to

the top (R_A) and the resistance from the slider to the bottom (R_B). The input voltage is applied across the series combination of R_A and R_B , the whole potentiometer. The output voltage is taken across R_B from the slider to the bottom.

Assume that the slider is at the top. In this case, R_A is zero and the entire input voltage is across R_B and appears across the output terminals. As the slider is moved downward, the resistance of R_A increases and part of the input voltage appears across R_A , with the rest of the input voltage appearing across R_B . Finally, when the slider is moved all the way down, R_B equals zero. As a result, all of the input voltage appears across R_A and there is no voltage across R_B or at the output terminals.

A potentiometer can therefore supply any desired portion of the input voltage to the output terminals, depending on the position of the slider. The familiar volume control on radio and TV receivers is nothing more than a potentiometer similar to the one shown in Figure 8. The same circuit is used in industrial control circuits, missile electronic systems, electronic computers and, in fact, the great majority of devices that control voltage.

Ohm's Law and Kirchhoff's voltage law are the basic "tools" for working with series circuits. For example, Figure 9 shows a circuit commonly used in digital computers. This circuit consists of a lamp in series with a transistor and a resistor. The transistor, indicated by the block, controls the lighting of the lamp according to the operations being performed by the computer. This provides the computer operator with a visible indication of circuit action.

The lamp shown in Figure 9 operates at 2.5 volts and draws a current of 50 mA (.05 ampere). Although it appears as though not enough information is given, we can use Ohm's Law together with Kirchhoff's voltage law to determine the resistance of the transistor, the voltages across R_1 and the transistor, and the total circuit resistance. Since this is a series circuit, the same current flows through each component. Since we know the resistance of R_1 , let's find its voltage drop by using Ohm's Law, $E=IR$:

$$E_{R_1} = 100 \times .05 = 1 \times 10^2 \times 5 \times 10^{-2} = 5 \text{ volts.}$$

Now the voltages across the lamp and R_1 are known. Kirchhoff's voltage law states that the sum of the voltage drops in a series circuit equals the supply voltage. The sum of the lamp voltage and the voltage across R_1 is $2.5 + 5 = 7.5$ volts. By Kirchhoff's voltage law, the transistor voltage plus 7.5 volts must equal the source voltage, 10 volts. Therefore, the voltage across the transistor is 10 volts minus 7.5 volts, or 2.5 volts.

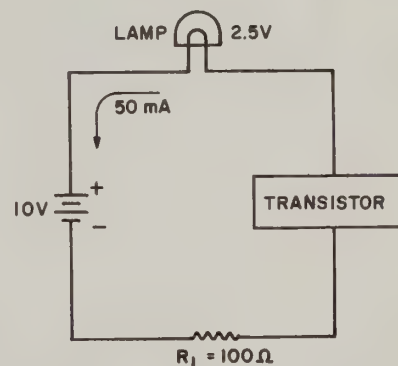


Figure
9



Speakers connected to a public address amplifier like the one shown above form a parallel circuit.

Courtesy Bogen Div., Lear-Siegler Inc.

Since the voltage and current are known, the resistance of the transistor can now be found by using Ohm's Law, $R=E/I$:

$$R_{\text{TRANSISTOR}} = \frac{2.5}{.05} = \frac{2.5}{5 \times 10^{-2}} = \frac{2.5 \times 10^2}{5}$$

$$= .5 \times 10^2 \text{ or } 50 \text{ ohms.}$$

In a similar manner, the resistance of the lamp can be found:

$$R_{\text{LAMP}} = \frac{2.5}{.05} = \frac{2.5}{5 \times 10^{-2}} = \frac{2.5 \times 10^2}{5}$$

$$= .5 \times 10^2 \text{ or } 50 \text{ ohms.}$$

The total circuit resistance can now be found simply by adding the individual resistances:

$$R_T = 50 + 50 + 100 = 200 \text{ ohms.}$$

You also could have found the total resistance by dividing the supply voltage by the circuit current, $R=E/I$:

$$R_T = \frac{10}{.05} = \frac{10}{5 \times 10^{-2}} = \frac{10 \times 10^2}{5}$$

$$= 2 \times 10^2 \text{ or } 200 \text{ ohms.}$$

Open-Circuit Voltage

Remember that the voltage across a component in a series circuit depends on its resistance. As the component resistance is increased, the voltage drop across it also increases. Examine the circuit shown in Figure 10. This circuit consists of a $1\text{ k}\Omega$ resistor (R_1) and a $99\text{ k}\Omega$ resistor (R_2) connected in series. Note that almost the entire source voltage appears across R_2 , with a very small voltage appearing across R_1 .

Now examine Figure 11. Here R_2 has been removed. With R_2 removed, the resistance between the points in the circuit where it was connected is infinite (∞), so high that it cannot be measured. As a result, the ENTIRE source voltage appears across the open, and zero volts appear across R_1 .

You might say that this cannot happen because once the circuit is open, no current flows and no voltages can be developed. However, Ohm's Law and Kirchhoff's voltage law can be used to prove that the supply voltage appears across the open. With the circuit open, the current through R_1 is zero and as a result the voltage drop across R_1 is also zero. However, Kirchhoff's voltage law states that the sum of the voltages in a series circuit equals the source voltage. Thus, if the voltage across R_1 is zero, the voltage across the open must equal the supply voltage.

The concept of open-circuit voltage is useful in many applications. One practical example is shown in Figure 12. This is the series string filament

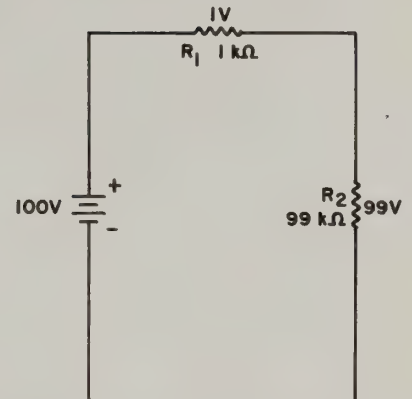


Figure
10

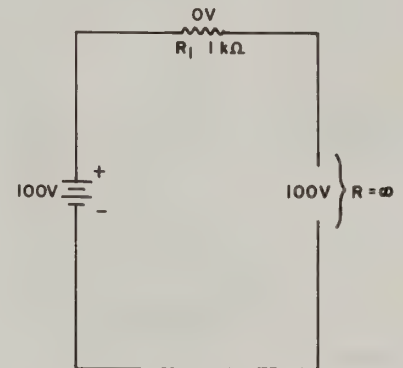


Figure
11

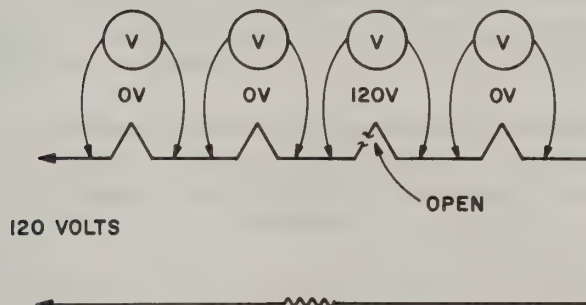


Figure 12

circuit shown earlier. One of the tube filaments has burned out and thus become an open circuit. You could find the defective filament by testing each tube. A much quicker method is to measure the voltage across each filament. You will measure zero volts across the good filaments and nearly the supply voltage will be measured across the open filament. If the meter were perfect, the meter would measure the supply voltage across the open. Instead, because of the meter resistance, the meter will indicate less than the supply voltage.

PARALLEL CIRCUITS

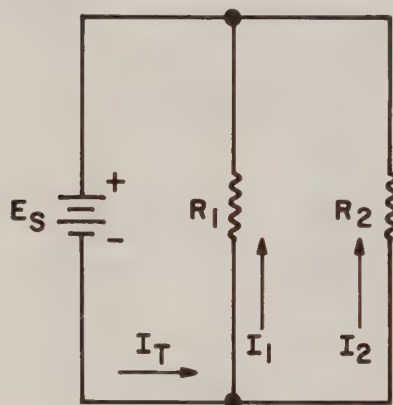


Figure 13

A parallel circuit has more than one current path. Figure 13 shows a parallel circuit with two current paths. The source voltage appears across each path or "branch." The sum of the individual branch currents, I_1 and I_2 , equals the total circuit current, I_T . As in a series circuit, the components in a parallel circuit need not be just resistors. Transistors, vacuum tubes, lamps, motors and other components can also make up a parallel circuit.

Figure 14 shows a parallel filament circuit. Notice that each filament is connected across or in parallel with the power supply. As a result, a separate current flows through each filament. If each filament has a different resistance, a different value of current flows through each filament. If each filament has the same resistance, the same amount of current flows through each filament. Note, under this last condition, that the same "amount," not the "same current," flows through each filament or branch of the circuit.

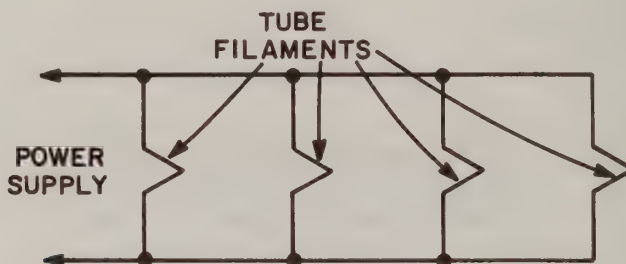


Figure 14

Determining Resistance in Parallel Circuits

Because current has more than one path in a parallel circuit, the total resistance of a parallel circuit is smaller than the smallest branch resistance.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

DC CIRCUITS

SERIES CIRCUITS

DETERMINING RESISTANCE IN SERIES CIRCUITS

CURRENT AND VOLTAGE IN SERIES CIRCUITS

KIRCHHOFF'S VOLTAGE LAW

OPEN-CIRCUIT VOLTAGE

1. Would combinations of series and parallel circuits be found in a pocket transistor receiver?
2. What is the distinguishing characteristic of a series circuit?
3. What is the total resistance of a series circuit that consists of four resistances: 10 k Ω , 350 Ω , 120 k Ω and 7.5 M Ω ?
4. Suppose that a series circuit consists of three lamps. If all three lamps require a current of 60 mA and operate at voltages of 3, 6 and 9 volts, respectively, what is the total resistance of the circuit?
5. Assume that your toaster operates on 120 volts and draws 10 amperes. What is the resistance of the toaster's heating element?
6. If the supply voltage in a series circuit increases and the resistance remains the same, the circuit current (a) remains the same, (b) increases, (c) decreases.
7. If the supply voltage in a series circuit remains the same and the total circuit resistance increases, the circuit current (a) increases, (b) decreases, (c) remains the same.
8. Suppose that an electric furnace has a resistance of 50 ohms and is controlled by a variable resistance connected in series with the furnace. If the supply voltage is 440 volts and the variable resistance is set at 60 ohms, how much current flows through the furnace?
9. Could you determine the total current in a series circuit if you did not know the supply voltage or the total circuit resistance?
10. A particular series circuit consists of a 3 k Ω resistor (R_1) and a 47 k Ω resistor (R_2) connected to a 250-volt source. What is the voltage drop across each resistor?

11. What is Kirchhoff's voltage law for series circuits?
12. As the slider of the potentiometer shown in Figure 8 is moved upward, the output voltage (a) increases, (b) decreases.
13. Assume that you wanted an output voltage exactly half of the input voltage shown in Figure 8. Where would you set the slider of the potentiometer, and what would the relation be between R_A and R_B ?
14. Assume that you are measuring the voltage drops across several resistors in a series circuit which has a supply voltage of 120 volts. If you get a reading of 120 volts across one resistor and 0 volts across the others, what is the probable fault?

There are a number of simple formulas which can be used to determine the total resistance of a parallel circuit. One of the most popular is the "product over the sum" formula. This relationship is used to determine the resistance of two parallel resistors. To show the use of the "product over the sum" formula, let's find the total resistance of the circuit shown in Figure 15. The "product over the sum" relationship is shown below:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

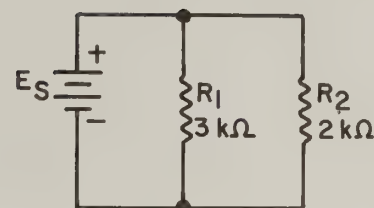


Figure
15

To determine the total resistance of the circuit shown in Figure 15, just substitute the values of R_1 and R_2 into this formula:

$$\begin{aligned} R_T &= \frac{R_1 \times R_2}{R_1 + R_2} = \frac{3\text{K} \times 2\text{K}}{3\text{K} + 2\text{K}} \\ &= \frac{3 \times 10^3 \times 2 \times 10^3}{3 \times 10^3 + 2 \times 10^3} = \frac{6 \times 10^6}{5 \times 10^3} \\ &= \frac{6 \times 10^6 \times 10^{-3}}{5} = 1.2 \times 10^3 \\ &= 1.2\text{K or } 1200 \text{ ohms.} \end{aligned}$$

(Remember, when you add numbers expressed in scientific notation, the exponents of 10 must be the same. If they are not, change one of the numbers so that the exponents of 10 in both numbers are the same.) Notice that the total resistance of the circuit shown in Figure 15 is 1.2 k Ω . This is less than the smallest branch resistance.

Although the "product over the sum" relationship includes only two resistances, it can also be used for circuits containing a greater number of parallel resistances. To use this formula, first find the equivalent resistance, R_{EQ} , of any two parallel resistors. It does not matter which two you choose. Then pick a remaining resistance and, together with the equivalent resistance of the other two resistances, use the formula again. Repeat this procedure until all the resistances in the circuit have been used.

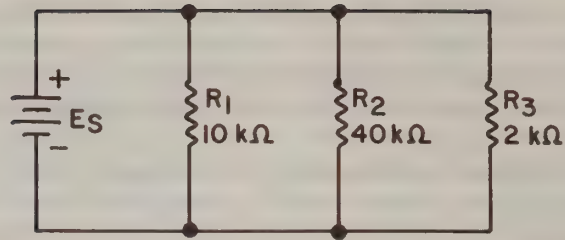


Figure 16

To show this method, let's determine the total resistance of the circuit shown in Figure 16. You can start by finding the total resistance of R_1 and R_2 :

$$R_{EQ} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{10K \times 40K}{10K + 40K} = \frac{1 \times 10^4 \times 4 \times 10^4}{1 \times 10^4 + 4 \times 10^4}$$

$$= \frac{4 \times 10^8}{5 \times 10^4} = \frac{4 \times 10^8 \times 10^{-4}}{5}$$

$$= .8 \times 10^4 = 8K \text{ or } 8000 \text{ ohms.}$$

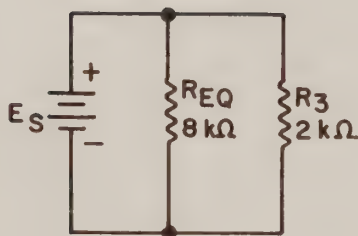


Figure 17

The equivalent resistance of R_1 and R_2 is therefore 8 kΩ or 8000 ohms. This equivalent resistance is in parallel with the remaining 2 kΩ resistor, as shown in Figure 17. The total resistance of the circuit can be found by applying the "product over the sum" relationship once again:

$$R_T = \frac{R_{EQ} \times R_3}{R_{EQ} + R_3} = \frac{8K \times 2K}{8K + 2K}$$

$$= \frac{8 \times 10^3 \times 2 \times 10^3}{8 \times 10^3 + 2 \times 10^3} = \frac{16 \times 10^6}{10 \times 10^3}$$

$$= \frac{16 \times 10^6 \times 10^{-3}}{10} = 1.6 \times 10^3$$

$$= 1.6K \text{ or } 1600 \text{ ohms.}$$

This identical procedure can be used for a parallel circuit with any number of resistances.



The amplifier stages in a tape recorder can often be analyzed as series circuits. These series circuits in turn form parallel circuits when connected to the power supply.

Courtesy Bell & Howell

Another method of determining the total resistance of a parallel circuit is by means of the following formula:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \text{etc.}}$$

This method is called the “reciprocal of the sum of the reciprocals” method. It is further illustrated in the Appendix.

The total resistance of a parallel circuit may also be found by using Ohm's Law, $R=E/I$, if the total circuit current and the supply voltage are known. As an example, let's determine the total resistance of the circuit shown in Figure 18. This circuit represents the various circuits in a portable transistor

radio receiver. Each circuit is connected across the 9-volt battery, and thus the circuits are in parallel with one another. This is a common arrangement in electronic equipment; the various circuits are usually in parallel with one another and with the supply.

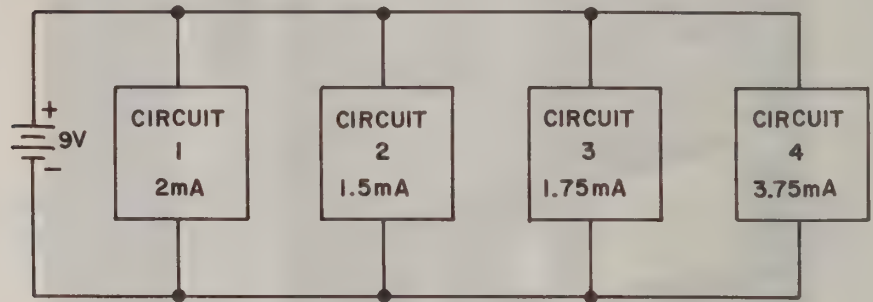


Figure 18

The currents drawn by each circuit are as shown in Figure 18. To determine the total circuit current, all you have to do is add the individual currents. Since the currents are all expressed in mA, you can add them directly:

$$I_T = 2 + 1.5 + 1.75 + 3.75 = 9 \text{ mA.}$$

The total circuit resistance can now be calculated by dividing the supply voltage in volts (9 volts) by the circuit current in amperes ($9 \text{ mA} = .009 \text{ ampere}$):

$$R_T = \frac{9}{.009} = \frac{9}{9 \times 10^{-3}} = \frac{9 \times 10^3}{9} = 1 \times 10^3$$

$$= 1\text{K or } 1000 \text{ ohms.}$$

This same method can be used to determine the individual branch resistances of a parallel circuit. For example, let's determine the resistance of Circuit 1 shown in Figure 18. This circuit draws 2 mA (.002 ampere) from the 9-volt battery. Its resistance is equal to the supply voltage divided by the current through Circuit 1:

$$R_1 = \frac{9}{.002} = \frac{9}{2 \times 10^{-3}} = \frac{9 \times 10^3}{2}$$

$$R_1 = 4.5 \times 10^3 = 4.5\text{K or } 4500 \text{ ohms.}$$

Following the same procedure, the resistance of Circuit 2 is:

$$R_2 = \frac{9}{.0015} = \frac{9}{1.5 \times 10^{-3}} = \frac{9 \times 10^3}{1.5}$$

$$R_2 = 6 \times 10^3 = 6K = 6000 \text{ ohms.}$$

The resistance of the other circuits can be found similarly.

In summary, **THE TOTAL RESISTANCE OF A PARALLEL CIRCUIT CAN BE FOUND BY USING THE “PRODUCT OVER THE SUM” RELATIONSHIP, BY DIVIDING THE SUPPLY VOLTAGE BY THE TOTAL CIRCUIT CURRENT, OR BY THE “RECIPROCAL OF THE SUM OF THE RECIPROCALS” METHOD.**

Current and Voltage in Parallel Circuits

In a parallel circuit, all the branches are connected across (in parallel with) the power supply. As a result, the same voltage (the supply voltage) appears across each branch. A parallel arrangement is therefore useful when a number of devices or components must be operated at the same voltage. For example, various appliances in your home are usually designed to operate at 120 volts. When you connect them to the electric outlets, you are actually connecting them across (in parallel with) the 120-volt power lines. In turn, each component is a separate branch and draws the required amount of current.

The current flowing through each branch of a parallel circuit depends on the resistance of that branch. The total circuit current is the sum of the branch currents. This relationship is often referred to as **KIRCHHOFF'S CURRENT LAW**.

Ohm's Law can be used to find the current flowing through the branches of a parallel circuit. As an example, let's determine the individual branch currents and the total circuit current of the circuit shown in Figure 19. Since

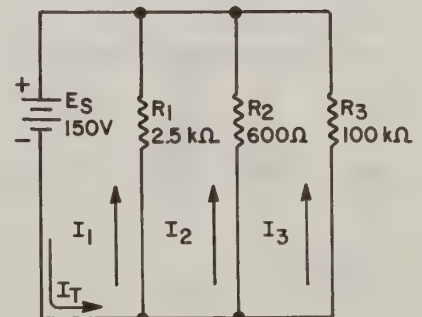


Figure 19

the resistance of each branch as well as the supply voltage is known, use Ohm's Law, $I=E/R$, to determine the current through each resistance:

$$I_1 = \frac{150}{2.5K} = \frac{1.5 \times 10^2}{2.5 \times 10^3} = \frac{1.5 \times 10^2 \times 10^{-3}}{2.5}$$

$$= .6 \times 10^{-1} = .06 \text{ ampere or } 60 \text{ mA.}$$

$$I_2 = \frac{150}{600} = \frac{1.5 \times 10^2}{6 \times 10^2} = \frac{1.5 \times 10^2 \times 10^{-2}}{6}$$

$$= .25 \times 10^0 = .25 \text{ ampere or } 250 \text{ mA.}$$

$$I_3 = \frac{150}{100K} = \frac{1.5 \times 10^2}{1 \times 10^5} = \frac{1.5 \times 10^2 \times 10^{-5}}{1}$$

$$= 1.5 \times 10^{-3} = .0015 \text{ ampere or } 1.5 \text{ mA.}$$

The total circuit current is equal to the sum of the three currents:

$$I_T = I_1 + I_2 + I_3$$

$$= .06 + .25 + .0015$$

$$= .3115 \text{ ampere}$$

or

$$I_T = 60 + 250 + 1.5 = 311.5 \text{ mA.}$$

If desired, the total circuit resistance could be found by dividing the supply voltage by the total circuit current.

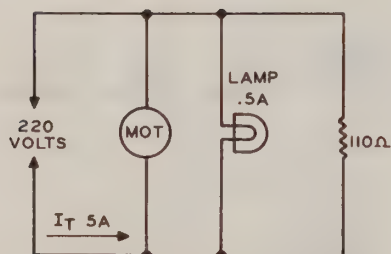


Figure
20

Kirchhoff's Current Law

In some cases the resistance of a particular component in a parallel circuit may not be known. The current through this component can be found by using Kirchhoff's current law if the total circuit current and the current in the other branches of the circuit are known. As an example, let's determine the motor current in the circuit shown in Figure 20. Note that the total

circuit current and the lamp current are known. The current through the 110Ω resistor can be found by using Ohm's Law ($I=E/R$):

$$I = \frac{220}{110} = 2 \text{ amperes.}$$

Kirchhoff's current law states that **THE SUM OF THE INDIVIDUAL BRANCH CURRENTS EQUALS THE TOTAL CIRCUIT CURRENT.** In Figure 20, the motor current plus the lamp current plus the resistor current equals the total circuit current of 5 amperes. Since the lamp current is .5 ampere and the current through the 110 ohm resistor is 2 amperes, the motor current is equal to $5 - (2 + .5)$ or 2.5 amperes.

In a series circuit, the voltages across the individual components depend on the resistance values of the components. However, in a parallel circuit the voltage is the same across each branch. The resistance of each branch in a parallel circuit determines the current through that branch. If the resistance of one branch is high, the current through that branch is then low. If the resistance of a branch is low, that branch current is then high. As branches are added to a parallel circuit, the additional branch currents increase the total circuit current. Remember, as additional **PARALLEL BRANCHES ARE ADDED**, the **TOTAL RESISTANCE** of the circuit **DECREASES**.

COMBINATION CIRCUITS

A combination circuit consists of series and parallel circuits. Most electronic equipment consists of combination circuits. To work with a combination circuit, all you need do is apply the methods of working with series and parallel circuits to the series and parallel sections of the combination circuit.

Figure 21 shows a combination circuit that is the basic circuit of a two-transistor amplifier. R_1 and Transistor 1 form one series circuit, while R_2 and Transistor 2 form another series circuit. These two series circuits are then connected in parallel with the supply, E_s .

To work on any combination circuit, just handle the series and parallel sections separately. Find the resistance of each series section or branch by adding the resistance of the transistor and the resistor. Then find the total circuit resistance by using the branch resistances in the "product over the sum" parallel resistance formula.

Find the current in each series branch by dividing the supply voltage, E_s , by the total resistance of each branch. To find the total circuit current, add

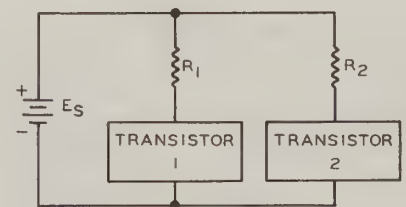


Figure 21

the branch currents. By using Ohm's Law ($E=IR$), you can find the voltage drop across the resistor and transistor in each branch.

Determining Combination Circuit Resistance

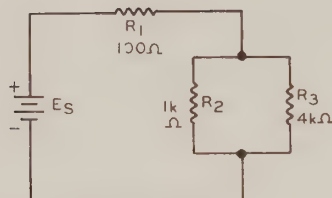


Figure
22

You can find the total resistance of a combination circuit by first determining the resistance of the series and parallel branches and then combining them. For example, let's determine the resistance of the combination circuit shown in Figure 22. This circuit consists of one resistor, R_1 , in series with two resistors in parallel, R_2 and R_3 . The total resistance of this circuit is equal to the value of R_1 plus the value of the parallel combination of R_2 and R_3 . To start the solution, use the "product over the sum" formula to determine the equivalent resistance of R_2 and R_3 :

$$\begin{aligned} R_{EQ} &= \frac{R_2 \times R_3}{R_2 + R_3} = \frac{1K \times 4K}{1K + 4K} = \frac{1 \times 10^3 \times 4 \times 10^3}{1 \times 10^3 + 4 \times 10^3} \\ &= \frac{4 \times 10^6}{5 \times 10^3} = \frac{4 \times 10^6 \times 10^{-3}}{5} \\ &= .8 \times 10^3 = 800 \text{ ohms.} \end{aligned}$$

Now find the total circuit resistance by adding the resistance of R_1 and the equivalent resistance of R_2 and R_3 :

$$R_T = 100 + 800 = 900 \text{ ohms.}$$

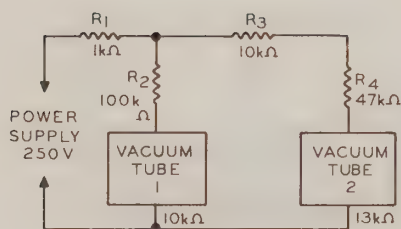


Figure
23

As another example, let's determine the total resistance of the circuit shown in Figure 23. This circuit represents a two vacuum tube amplifier.

The combination circuit shown in Figure 23 consists, first of all, of two series circuits— R_2 in series with Vacuum Tube 1, and R_3 and R_4 in series with Vacuum Tube 2. These two series circuits are connected in parallel, and the parallel arrangement is in series with R_1 . This circuit looks involved, but it can be analyzed in sections using the same methods used for the simple series and parallel circuits. For example, let's determine the total resistance seen at the power supply terminals.

First, find the resistance of each branch by merely adding the resistances. Next, find the equivalent resistance of the two branches. Finally, add this equivalent resistance to R_1 to obtain the total circuit resistance.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

PARALLEL CIRCUITS

DETERMINING RESISTANCE IN PARALLEL CIRCUITS

CURRENT AND VOLTAGE IN PARALLEL CIRCUITS

KIRCHHOFF'S CURRENT LAW

15. What is a parallel circuit?
16. If each filament in the circuit shown in Figure 14 has the same resistance, does the same amount of current flow through each filament?
17. Is the voltage applied to each filament shown in Figure 14 the same?
18. How does the total resistance of a parallel circuit compare to the resistance of the individual branch resistances in the circuit?
19. Can you use the "product over the sum" formula to determine the total resistance of three parallel connected resistances?
20. What is the total resistance of a parallel circuit consisting of two 50 k Ω resistors and a 25 k Ω resistor?
21. Can the total resistance of a parallel circuit be found using Ohm's Law?
22. Assume that you measure the current drawn by two circuits and obtain 1.2 amperes and 800 mA. What is the total resistance of these circuits if they are connected in parallel to a 440-volt supply?
23. Adding another resistance to a parallel circuit would cause the total resistance of the parallel circuit to (a) increase, (b) decrease, (c) remain the same.

24. Assume that you built a circuit using three vacuum tubes with 6.3-volt heaters. Would you connect them in series or parallel if the three tube heaters required different currents?
25. What is the total circuit current in a parallel circuit consisting of a $25\text{ k}\Omega$ and a $200\text{ k}\Omega$ resistor connected across a 500-volt source?
26. What is Kirchhoff's current law for a parallel circuit?
27. Two transistor amplifier circuits are connected across or in parallel with a 9-volt battery. If the total circuit current is 5 mA and the current through one of the amplifier circuits is 1.75 mA, what is the current through the other amplifier circuit?
28. The branch that has the lowest resistance in a parallel circuit carries the (a) lowest current, (b) highest current.
29. If you know the total circuit current for the circuit shown in Figure 20, and you also know the motor and lamp currents, can you determine the current in the resistor?

To determine the resistance of R_2 and Vacuum Tube 1, just add their resistances:

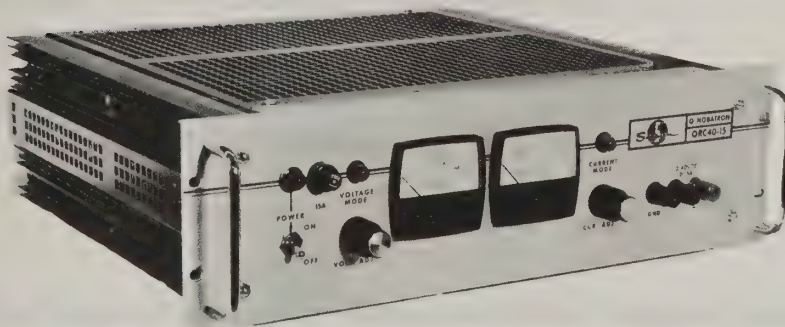
$$R_{EQ_1} = 100K + 10K = 110 \text{ k}\Omega.$$

(Remember, if the resistances are all expressed in $k\Omega$ or megohms, they can be directly added.) The resistance of the other series branch can be found similarly:

$$R_{EQ_2} = 10K + 47K + 13K = 70 \text{ k}\Omega.$$

The equivalent resistance of the two branches is now determined by using the "product over the sum" formula for parallel resistance:

$$R_{EQ_3} = \frac{110K \times 70K}{110K + 70K} = \frac{11 \times 10^4 \times 7 \times 10^4}{11 \times 10^4 + 7 \times 10^4}$$



*This dc power supply is designed to provide low voltages at high currents.
Courtesy Raytheon Co., Sorensen Operation*

(NOTE: The resistance of the 110K resistor is left as 11×10^4 rather than 1.1×10^5 .)

$$R_{EQ_3} = \frac{77 \times 10^8}{18 \times 10^4} = \frac{77 \times 10^8 \times 10^{-4}}{18} = \frac{77 \times 10^4}{18}$$

$$R_{EQ_3} = 4.2777 \dots \times 10^4 \text{ ohms.}$$

When dividing 77 by 18, you cannot obtain an exact answer. Continuing the division only adds more 7's to the answer. Answers like this are often encountered. In this case, "round off" the number and obtain an approximate answer. To round off any number to three digits, write down the first four digits of the number. Look at the fourth digit (the one on the right). If it is less than 5, just drop it. If it is 5 or more, add 1 to the third digit in the number and drop all digits which follow it. R_{EQ3} is "rounded off" as follows:

$$4.27\cancel{7} \text{ Drop the 7 and add 1} \\ = 4.28$$

The approximate parallel resistance is therefore 42.8K ohms. Since this process results in a three-digit number, it is called "rounding off to three significant figures." A few more examples of the method of "rounding off" follow:

$$1753 = 175\cancel{3} \text{ Drop the 3} \\ = 1750 \text{ (Note: Since no decimal point is shown, it is assumed to be after the digit 3. Therefore, we replace the digit 3 with the digit 0.)}$$

$$1.255 = 1.25\cancel{5} \text{ Drop the 5 and add 1} \\ = 1.26$$

Returning to Figure 23, the total resistance of the circuit can now be found by adding R_1 to the approximate resistance of the parallel section:

$$R_T = 42.8K + 1K = 43.8K \text{ or } 43,800 \text{ ohms.}$$

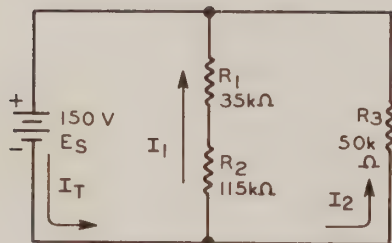


Figure
24

Voltage and Current in a Combination Circuit

Voltage and current in a combination circuit are found in much the same way as resistance is found: by working on each section of the circuit separately. As an example, let's determine the current through and the voltage across R_1 , R_2 and R_3 in the circuit of Figure 24. Since this is a parallel circuit, the source voltage appears across the series combination of R_1 and R_2 , as well as across R_3 .

The current flowing through R_3 (I_2) can be found by using Ohm's Law, $I=E/R$:

$$\begin{aligned} I_2 &= \frac{E_s}{R_3} = \frac{150}{50K} \\ &= \frac{15 \times 10^1}{5 \times 10^4} = \frac{15 \times 10^1 \times 10^{-4}}{5} \\ &= 3 \times 10^{-3} = .003 \text{ ampere or } 3 \text{ mA.} \end{aligned}$$

The total resistance of the R_1R_2 branch is found by adding the values of R_1 and R_2 :

$$R = R_1 + R_2 = 35K + 115K = 150K \text{ or } 150,000 \text{ ohms.}$$

The current flowing through the R_1R_2 (I_1) branch is also found by using Ohm's Law:

$$\begin{aligned} I_1 &= \frac{150}{150K} = \frac{1.5 \times 10^2}{1.5 \times 10^5} = \frac{1.5 \times 10^2 \times 10^{-5}}{1.5} \\ &= 1 \times 10^{-3} = .001 \text{ ampere or } 1 \text{ mA.} \end{aligned}$$

Since the circuit shown in Figure 24 is a parallel circuit with a series circuit forming one branch, the total circuit current is the sum of the branch currents:

$$I_T = I_1 + I_2 = 3 + 1 = 4 \text{ mA or } .004 \text{ ampere.}$$

If desired, the total circuit resistance could be found by dividing the source voltage by the total circuit current:

$$R_T = \frac{150}{.004} = \frac{15 \times 10^1}{4 \times 10^{-3}} = \frac{15 \times 10^1 \times 10^3}{4}$$

$$R_T = 3.75 \times 10^4 = 37.5K \text{ or } 37,500 \text{ ohms.}$$

Examine the circuit shown in Figure 24. Note that the total resistance of the circuit (37.5 k Ω) is less than the smallest branch resistance in the circuit (50 k Ω). Remember, this relationship always holds true for a parallel circuit.

The voltage across R_3 is equal to the supply voltage (150 volts) since this is a parallel circuit. The supply voltage also appears across the series combination of R_1 and R_2 . Ohm's Law, $E=IR$, can be used to determine the voltages across R_1 and R_2 . The current value to use is the current flowing through the R_1R_2 branch (1 mA or .001 ampere):

$$\begin{aligned} E_{R_1} &= .001 \times 35K = 1 \times 10^{-3} \times 3.5 \times 10^4 \\ &= 3.5 \times 10^1 = 35 \text{ volts.} \end{aligned}$$

$$\begin{aligned} E_{R_2} &= .001 \times 115K = 1 \times 10^{-3} \times 1.15 \times 10^5 \\ &= 1.15 \times 10^2 = 115 \text{ volts.} \end{aligned}$$

To check the answers, add them together. The sum of the voltages across R_1 and R_2 should equal the source voltage (Kirchhoff's Law):

$$E_s = 35 + 115 = 150 \text{ volts.}$$

As another example, let's determine the voltage and current in the combination circuit of Figure 25.

This circuit consists of two parallel circuits connected in series. To determine the total circuit current, you must first find the equivalent resistance of each parallel circuit. If you add the equivalent resistances together, you will get the total circuit resistance. Use this total resistance and the supply voltage to find the total circuit current by using Ohm's Law.

First, let's use the "product over the sum" formula to determine the equivalent resistances of the two parallel circuits:

$$\begin{aligned} R_{EQ1} &= \frac{R_1 \times R_2}{R_1 + R_2} = \frac{1K \times 4K}{1K + 4K} \\ &= \frac{1 \times 10^3 \times 4 \times 10^3}{1 \times 10^3 + 4 \times 10^3} = \frac{4 \times 10^6}{5 \times 10^3} \\ &= \frac{4 \times 10^6 \times 10^{-3}}{5} = .8 \times 10^3 = .8K \text{ or } 800 \text{ ohms.} \end{aligned}$$

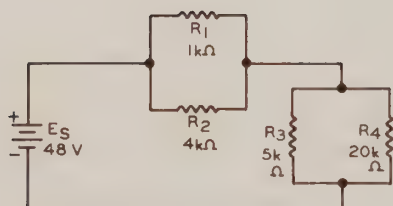


Figure
25

$$\begin{aligned}
 R_{EQ_2} &= \frac{R_3 \times R_4}{R_3 + R_4} = \frac{5K \times 20K}{5K + 20K} \\
 &= \frac{5 \times 10^3 \times 20 \times 10^3}{5 \times 10^3 + 20 \times 10^3} = \frac{100 \times 10^6}{25 \times 10^3} \\
 &= \frac{100 \times 10^6 \times 10^{-3}}{25} = 4 \times 10^3 = 4K \text{ or } 4000 \text{ ohms.}
 \end{aligned}$$

The total circuit resistance is the sum of the equivalent resistances:

$$R_T = R_{EQ_1} + R_{EQ_2} = 4K + 800 = 4800 \text{ or } 4.8K \text{ ohms.}$$

Using Ohm's Law to find the total circuit current:

$$I_T = \frac{E_S}{R_T} = \frac{48}{4.8K} = \frac{48}{4.8 \times 10^3} = \frac{48 \times 10^{-3}}{4.8}$$

$$I_T = 10 \times 10^{-3} = .01 \text{ ampere or } 10 \text{ mA.}$$

Since this is basically a series circuit, the 10 mA flows through each parallel section. Therefore, the sum of the currents in each parallel section equals 10 mA. To determine the current through each resistance, you must know the voltage across the resistance. The voltage across each parallel section is found by multiplying the circuit current by the resistance of each parallel section:

$$E_{R_{EQ_1}} = I_T \times R_{EQ_1} = .01 \times 800 = 10 \times 10^{-3} \times 8 \times 10^2$$

$$= 80 \times 10^{-1} = 8 \text{ volts.}$$

$$E_{R_{EQ_2}} = I_T \times R_{EQ_2} = .01 \times 4K = 10 \times 10^{-3} \times 4 \times 10^3$$

$$= 40 \text{ volts.}$$

Notice that the sum of the voltages across the parallel sections equals the source voltage (Kirchhoff's Law). Now the currents flowing through the resistors can be found by using Ohm's Law ($I=E/R$):

$$I_{R_1} = \frac{E_{R_{EQ1}}}{R_1} = \frac{8}{1K} = \frac{8}{1 \times 10^3} = \frac{8 \times 10^{-3}}{1}$$

$$= 8 \times 10^{-3} = .008 \text{ ampere or } 8 \text{ mA.}$$

$$I_{R_2} = \frac{E_{R_{EQ1}}}{R_2} = \frac{8}{4K} = \frac{8}{4 \times 10^3} = \frac{8 \times 10^{-3}}{4}$$

$$= 2 \times 10^{-3} = .002 \text{ ampere or } 2 \text{ mA.}$$

The sum of I_{R_1} and I_{R_2} should equal the total circuit of 10 mA (Kirchhoff's current law). The currents through R_3 and R_4 can be found similarly:

$$I_{R_3} = \frac{40}{5K} = \frac{40}{5 \times 10^3} = \frac{40 \times 10^{-3}}{5}$$

$$= 8 \times 10^{-3} = .008 \text{ ampere or } 8 \text{ mA.}$$

$$I_{R_4} = \frac{40}{20K} = \frac{40}{2 \times 10^4} = \frac{40 \times 10^{-4}}{2}$$

$$= 20 \times 10^{-4} = .002 \text{ ampere or } 2 \text{ mA.}$$

Notice that the sum of I_{R_3} and I_{R_4} also equals the total circuit current of 10 mA.

SUMMARY

A series circuit has one current path while a parallel circuit has two or more current paths. The total resistance of a series circuit is found by adding the individual resistances. The "product over the sum" formula can be used to determine the total resistance of a parallel circuit. The voltages and currents in series and parallel circuits are found by using the appropriate forms of Ohm's Law.

The following Practice Exercise questions cover the subjects which you have just studied. They are:

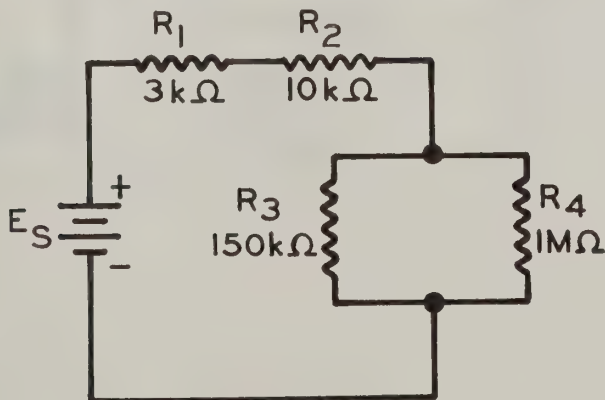
COMBINATION CIRCUITS

DETERMINING COMBINATION CIRCUIT RESISTANCE

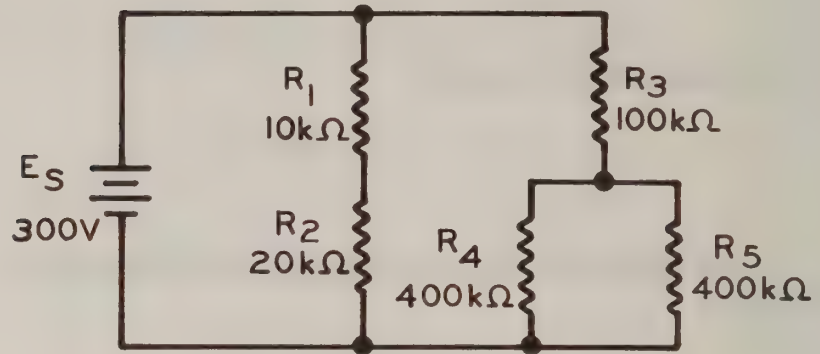
VOLTAGE AND CURRENT IN A COMBINATION CIRCUIT

30. Round off the following numbers to three significant figures: (a) 1755; (b) 1.6333; (c) 95.19.

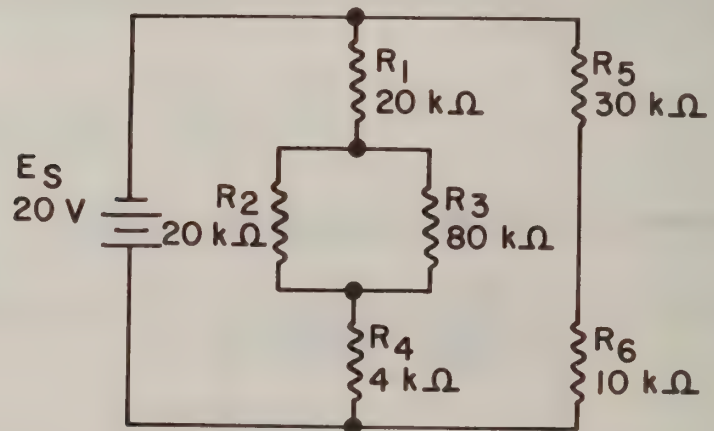
31. Determine the total resistance of the circuit shown below.



32. Determine the voltage across each component as well as the current through each component in the circuit shown below.



33. Determine the voltage across each component as well as the current through each component in the circuit shown below.



In a series circuit, the sum of the voltage drops across the components equals the supply voltage. This is known as Kirchhoff's voltage law. In a parallel circuit, the sum of the branch currents equals the total circuit current. This is known as Kirchhoff's current law.

A combination circuit is merely a combination of series and parallel circuits. Simply apply the methods of working with series and parallel circuits to the series and parallel sections.

APPENDIX

PARALLEL RESISTANCE FORMULA

The "reciprocal of the sum of the reciprocals" formula used to determine the resistance of a parallel circuit is shown below:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \text{etc.}}$$

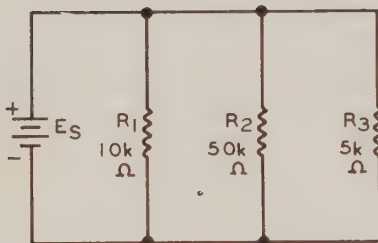


Figure
26

This formula can be used to determine the resistance of any number of resistors connected in parallel. To illustrate the use of this formula, let's determine the total resistance of the circuit of Figure 26. Substitute the values of the resistances in the formula as shown below:

$$R_T = \frac{1}{\frac{1}{10K} + \frac{1}{50K} + \frac{1}{5K}}$$

$$= \frac{1}{\frac{1}{1 \times 10^4} + \frac{1}{5 \times 10^4} + \frac{1}{5 \times 10^3}}$$

Now divide the 1's in the lower half by the resistance values:

$$R_T = \frac{1}{1 \times 10^{-4} + .2 \times 10^{-4} + .2 \times 10^{-3}}$$

Next, add the quantities in the bottom of the formula. Remember, the exponents of ten must all be the same. In this case you can change $.2 \times 10^{-3}$ to 2×10^{-4} :

$$R_T = \frac{1}{1 \times 10^{-4} + .2 \times 10^{-4} + 2 \times 10^{-4}}$$

$$= \frac{1}{3.2 \times 10^{-4}}$$

$$= \frac{1}{3.2 \times 10^{-4}} = \frac{1 \times 10^4}{3.2}$$

APPENDIX (Continued)

To complete the problem, just divide 1 by 3.2:

$$R_T = .3125 \times 10^4 = 3125 \text{ or } 3.125 \text{ k}\Omega \text{ or approximately } 3.13 \text{ k}\Omega.$$

As another example, the total resistance of the circuit shown in Figure 27 is calculated as follows:

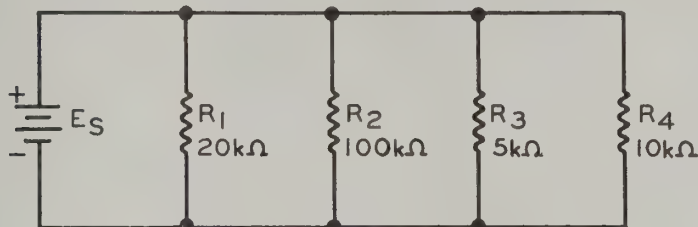


Figure 27

$$\begin{aligned} R_T &= \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}} \\ &= \frac{1}{\frac{1}{2 \times 10^4} + \frac{1}{1 \times 10^5} + \frac{1}{5 \times 10^3} + \frac{1}{1 \times 10^4}} \\ &= \frac{1}{.5 \times 10^{-4} + 1 \times 10^{-5} + .2 \times 10^{-3} + 1 \times 10^{-4}} \\ &= \frac{1}{.5 \times 10^{-4} + .1 \times 10^{-4} + 2 \times 10^{-4} + 1 \times 10^{-4}} \\ &= \frac{1}{3.6 \times 10^{-4}} \\ &= \frac{1 \times 10^4}{3.6} \\ &= \text{approximately } .278 \times 10^4 \\ &= 2780 \text{ or } 2.78 \text{ k}\Omega. \end{aligned}$$

IMPORTANT DEFINITIONS

COMBINATION CIRCUIT — A circuit consisting of a combination of series and parallel circuits.

KIRCHHOFF'S CURRENT LAW — The sum of the branch currents flowing through a parallel circuit equals the total circuit current.

KIRCHHOFF'S VOLTAGE LAW — The sum of the voltage drops in a series circuit equals the supply voltage.

PRACTICE EXERCISE SOLUTIONS

1. Yes — Transistor receivers as well as most electronic equipment include combinations of series and parallel circuits.
2. The distinguishing characteristic of a series circuit is that it has one and only one current path.
3. 7,630,350 ohms. — To determine the total resistance, add the values of the individual resistances:

$$R_T = 10,000 + 350 + 120,000 + 7,500,000 = 7,630,350 \text{ ohms.}$$

4. 300 ohms. — To determine the resistance of each lamp, divide its voltage by the circuit current. Then add the lamp resistance to obtain the total resistance:

$$R_{\text{LAMP } 1} = \frac{3}{6 \times 10^{-2}} = .5 \times 10^2 \text{ or } 50 \text{ ohms.}$$

$$R_{\text{LAMP } 2} = \frac{6}{6 \times 10^{-2}} = 1 \times 10^2 \text{ or } 100 \text{ ohms.}$$

$$R_{\text{LAMP } 3} = \frac{9}{6 \times 10^{-2}} = 1.5 \times 10^2 \text{ or } 150 \text{ ohms.}$$

$$R_T = 50 + 100 + 150 = 300 \text{ ohms.}$$

5. 12 ohms. — To determine the resistance of the toaster's heating element, use Ohm's Law, $R=E/I$:

$$R = \frac{120}{10} = 12 \text{ ohms.}$$

6. (b) increases.

7. (b) decreases.

PRACTICE EXERCISE SOLUTIONS (Continued)

8. 4 amperes. — The circuit current is found by using Ohm's Law:

$$I = \frac{E}{R} = \frac{440}{60 + 50} = \frac{440}{110} = 4 \text{ amperes.}$$

9. Yes — However, you would have to know the resistance of one of the components and the voltage across that component. Since the current is the same in all parts of a series circuit, the current through any one component is the same as the total current.
10. The voltage drop across the 3 k Ω resistor is 15 volts, and the voltage drop across the 47 k Ω resistor is 235 volts. — To determine the voltage drops, first determine the total circuit resistance and then the circuit current. Then the individual voltage drops can be found:

$$R_T = 3K + 47K = 50 \text{ k}\Omega.$$

$$I = \frac{250}{50K} = \frac{2.5 \times 10^2}{5 \times 10^4} = \frac{2.5 \times 10^2 \times 10^{-4}}{5}$$

$$= .5 \times 10^{-2} \text{ or } .005 \text{ ampere (5 mA).}$$

$$E_{R_1} = 3K \times .005 = 3 \times 10^3 \times 5 \times 10^{-3} = 15 \text{ volts.}$$

$$E_{R_2} = 47K \times .005 = 4.7 \times 10^4 \times 5 \times 10^{-3}$$

$$= 23.5 \times 10^1 = 235 \text{ volts.}$$

11. Kirchhoff's voltage law states that the sum of the individual voltage drops in a series circuit equals the supply voltage.
12. (a) increases.
13. The slider would be set in the center so that $R_A = R_B$.
14. The resistor across which you measure 120 volts is open.

PRACTICE EXERCISE SOLUTIONS (Continued)

15. A parallel circuit is a circuit that has more than one current path.
16. Yes — In this case the same “amount” of current flows through each filament. However, the “same current” does not flow through each filament as it does in a series circuit.
17. Yes — Since each filament is connected across or in parallel with the supply, the same voltage is applied across each filament.
18. The total resistance of a parallel circuit is less than the resistance of the smallest resistance branch.
19. Yes — First you find the equivalent resistance of two of the resistances. Then, use that equivalent resistance and the other resistance to determine the total circuit resistance.
20. 12.5K or 12,500 ohms. — Finding the equivalent of the two 50 kΩ resistors yields:

$$R_{EQ} = \frac{5 \times 10^4 \times 5 \times 10^4}{5 \times 10^4 + 5 \times 10^4} = \frac{25 \times 10^8}{10 \times 10^4}$$

$$= 2.5 \times 10^4 = 25K \text{ or } 25,000 \text{ ohms.}$$

The “product over the sum” relationship is used again to find the total resistance:

$$R_T = \frac{2.5 \times 10^4 \times 2.5 \times 10^4}{2.5 \times 10^4 + 2.5 \times 10^4} = \frac{6.25 \times 10^8}{5 \times 10^4}$$

$$= 1.25 \times 10^4 = 12.5K \text{ or } 12,500 \text{ ohms.}$$

21. Yes — The total resistance of a parallel circuit is equal to the supply voltage divided by the total circuit current ($R=E/I$).

PRACTICE EXERCISE SOLUTIONS (Continued)

22. 220 ohms. — The total circuit current is equal to 1.2 amperes + .8 ampere (800 mA) or 2 amperes. The total circuit resistance is then equal to the supply voltage divided by the total circuit current:

$$R_T = \frac{440}{2} = 220 \text{ ohms.}$$

23. (b) decrease.
24. You should connect them in parallel if the heaters require different currents. To connect the heaters in series, they must all require the same current.
25. .0225 ampere or 22.5 mA. — The individual resistor currents are found by using Ohm's Law, $I = E/R$, and the total circuit current is the sum of the individual circuit currents:

$$I_1 = \frac{500}{25K} = \frac{5 \times 10^2}{2.5 \times 10^4} = \frac{5 \times 10^2 \times 10^{-4}}{2.5}$$

$$I_1 = 2 \times 10^{-2} = .02 \text{ ampere or } 20 \text{ mA.}$$

$$I_2 = \frac{500}{200K} = \frac{5 \times 10^2}{2 \times 10^5} = \frac{5 \times 10^2 \times 10^{-5}}{2}$$

$$I_2 = 2.5 \times 10^{-3} = .0025 \text{ ampere or } 2.5 \text{ mA.}$$

$$I_T = .02 + .0025 = .0225 \text{ amp}$$

or

$$I_T = 20 + 2.5 = 22.5 \text{ mA.}$$

26. The total circuit current is the sum of the individual branch currents.
27. 3.25 mA. — Using Kirchhoff's current law, the current through the other transistor amplifier is 5 — 1.75, or 3.25 mA.

PRACTICE EXERCISE SOLUTIONS (Continued)

28. (b) highest current.
29. Yes — The current in the resistor can be found by using Kirchhoff's current law, which states that the total circuit current is the sum of the individual branch currents. Since this is the case, the current through the resistor is equal to the total circuit current minus the motor and lamp currents.
30. (a) $1755 = 1760$; (b) $1.6333 = 1.63$; (c) $95.19 = 95.2$
31. Approximately 143 k Ω . — The parallel resistance of R_3 and R_4 is found by using the "product over the sum" relationship:

$$\begin{aligned}
 R_{EQ} &= \frac{150K \times 1Meg}{150K + 1Meg} = \frac{1.5 \times 10^5 \times 10 \times 10^5}{1.5 \times 10^5 + 10 \times 10^5} \\
 &= \frac{15 \times 10^{10}}{11.5 \times 10^5} = \frac{15 \times 10^{10} \times 10^{-5}}{11.5} \\
 &= 1.304 \dots \times 10^5 \text{ (round off to } 1.30 \times 10^5)
 \end{aligned}$$

$$R_{EQ} = \text{approximately } 130K \text{ or } 130,000 \text{ ohms.}$$

To obtain the total resistance, add this to the sum of R_1 and R_2 :

$$\begin{aligned}
 R_T &= 130K + 10K + 3K \\
 &= \text{approximately } 143K \text{ or } 143,000 \text{ ohms.}
 \end{aligned}$$

32. $E_{R_1} = 100V$, $I_{R_1} = 10 \text{ mA}$, $E_{R_2} = 200V$, $I_{R_2} = 10 \text{ mA}$, $E_{R_3} = 100V$, $I_{R_3} = 1 \text{ mA}$, $E_{R_4} = 200V$, $I_{R_4} = .5 \text{ mA}$, $E_{R_5} = 200V$, $I_{R_5} = .5 \text{ mA}$. — The resistance of the R_1R_2 series section is merely the sum of R_1 and R_2 :

$$R_1 + R_2 = 10K + 20K = 30K \text{ ohms.}$$

PRACTICE EXERCISE SOLUTIONS (Continued)

The current through R_1 and R_2 (I_1) is then found by using Ohm's Law ($I=E/R$):

$$I_1 = \frac{300}{30K} = \frac{3 \times 10^2}{3 \times 10^4} = \frac{3 \times 10^2 \times 10^{-4}}{3}$$

$$= 1 \times 10^{-2} = .01 \text{ ampere or } 10 \text{ mA.}$$

The voltage drops across R_1 and R_2 can now be found by multiplying the resistances of R_1 and R_2 by the currents through them:

$$E_{R_1} = 1 \times 10^{-2} \times 1 \times 10^4$$

$$= 1 \times 10^2 = 100 \text{ volts.}$$

$$E_{R_2} = 1 \times 10^{-2} \times 2 \times 10^4$$

$$= 2 \times 10^2 = 200 \text{ volts.}$$

The resistance of the other branch is R_3 in series with the parallel combination of R_4 and R_5 . The "product over the sum" formula can be used to determine the equivalent resistance of R_4 and R_5 :

$$R_{EQ} = \frac{400K \times 400K}{400K + 400K} = \frac{4 \times 10^5 \times 4 \times 10^5}{4 \times 10^5 + 4 \times 10^5}$$

$$= \frac{16 \times 10^{10}}{8 \times 10^5} = \frac{16 \times 10^{10} \times 10^{-5}}{8}$$

$$= 2 \times 10^5 = 200K \text{ or } 200,000 \text{ ohms.}$$

The total resistance of this branch is now determined by adding the resistance of R_3 to the parallel resistance of R_4 and R_5 :

$$R_3 + R_{EQ} = 200K + 100K = 300K \text{ ohms.}$$

PRACTICE EXERCISE SOLUTIONS (Continued)

Ohm's Law ($I=E/R$) is used to determine the current through this branch:

$$I_{R_3} = \frac{300}{300K} = \frac{3 \times 10^2}{3 \times 10^5} = \frac{3 \times 10^2 \times 10^{-5}}{3}$$

$$= 1 \times 10^{-3} = .001 \text{ ampere or } 1 \text{ mA.}$$

The voltage drop across R_3 is now found:

$$E_{R_3} = I_{R_3} \times R_3 = .001 \times 100K = 1 \times 10^{-3} \times 1 \times 10^5$$

$$= 1 \times 10^2 = 100 \text{ volts.}$$

The voltage across the parallel combination R_{EQ} is found by multiplying the branch current by the equivalent resistance:

$$E_{R_{EQ}} = .001 \times 200K = 1 \times 10^{-3} \times 2 \times 10^5$$

$$= 2 \times 10^2 = 200 \text{ volts.}$$

Now the currents in R_4 and R_5 can be found:

$$I_{R_4} = \frac{200}{400K} = \frac{2 \times 10^2}{4 \times 10^5} = \frac{2 \times 10^2 \times 10^{-5}}{4}$$

$$= .5 \times 10^{-3} = .0005 \text{ ampere or } .5 \text{ mA.}$$

$$I_{R_5} = \frac{200}{400K} = \frac{2 \times 10^2}{4 \times 10^5} = \frac{2 \times 10^2 \times 10^{-5}}{4}$$

$$= .5 \times 10^{-3} = .0005 \text{ ampere or } .5 \text{ mA.}$$

33. $E_{R_1} = 10V$, $I_{R_1} = .5 \text{ mA}$, $E_{R_2} = 8V$, $I_{R_2} = .4 \text{ mA}$, $E_{R_3} = 8V$, $I_{R_3} = .1 \text{ mA}$, $E_{R_4} = 2V$, $I_{R_4} = .5 \text{ mA}$, $E_{R_5} = 15V$, $I_{R_5} = .5 \text{ mA}$, $E_{R_6} = 5V$, $I_{R_6} = .5 \text{ mA}$.

PRACTICE EXERCISE SOLUTIONS (Continued)

The series resistance of the R_5R_6 series section is merely the sum of R_5 and R_6 :

$$R_5 + R_6 = 30K + 10K = 40K \text{ ohms.}$$

The current through R_5 and R_6 (I_2) is then found by using Ohm's Law ($I=E/R$):

$$\begin{aligned} I_2 &= \frac{20V}{40K} = \frac{2 \times 10^1}{4 \times 10^4} = \frac{2 \times 10^1 \times 10^{-4}}{4} \\ &= .5 \times 10^{-3} = .0005 \text{ ampere or } .5 \text{ mA.} \end{aligned}$$

The voltage drops across R_5 and R_6 can now be found by multiplying the resistances of R_5 and R_6 by the currents through them:

$$E_{R_5} = 5 \times 10^{-4} \times 3 \times 10^4 = 15 \text{ volts.}$$

$$E_{R_6} = 5 \times 10^{-4} \times 1 \times 10^4 = 5 \text{ volts.}$$

Now find the equivalent resistance of the R_2R_3 branch:

$$\begin{aligned} R_{EQ} &= \frac{R_2 \times R_3}{R_2 + R_3} = \frac{20 \times 10^3 \times 80 \times 10^3}{20 \times 10^3 + 80 \times 10^3} \\ &= \frac{1600 \times 10^6}{100 \times 10^3} = \frac{16 \times 10^8}{1 \times 10^5} = \frac{16 \times 10^8 \times 10^{-5}}{1} \\ &= 16 \times 10^3 = 16K \text{ ohms.} \end{aligned}$$

Next find the total resistance in the $R_1R_2R_3R_4$ branch by adding R_1 and R_4 to R_{EQ} :

$$R_1 + R_4 + R_{EQ} = 20K + 16K + 4K = 40 \text{ k}\Omega.$$

The current through this branch (I_1) is then found by using Ohm's Law ($I=E/R$):

$$\begin{aligned} I_1 &= \frac{20V}{40K} = \frac{2 \times 10^1}{4 \times 10^4} = \frac{2 \times 10^1 \times 10^{-4}}{4} \\ &= .5 \times 10^{-3} = .0005 \text{ ampere or } .5 \text{ mA.} \end{aligned}$$

PRACTICE EXERCISE SOLUTIONS (Continued)

Since this total current is flowing through R_1 and R_4 , their voltage drops can be found by multiplying their resistances by the current through them:

$$E_{R_1} = 5 \times 10^{-4} \times 2 \times 10^4 = 10 \text{ volts.}$$

$$E_{R_4} = 5 \times 10^{-4} \times 4 \times 10^3 = 20 \times 10^{-1} = 2 \text{ volts.}$$

Next find the voltage drop across the parallel resistances of R_2 and R_3 .

Since a total of 20 volts is applied to this branch, and the voltage dropped across R_1 and R_4 is 12 volts ($E_{R_1} + E_{R_4} = 10\text{V} + 2\text{V} = 12\text{V}$), the remainder, or 8 volts ($20\text{V} - 12\text{V} = 8\text{V}$), must be dropped across the parallel resistances of R_2 and R_3 .

To find the current through R_2 and R_3 , merely use Ohm's Law ($I = E/R$):

$$I_{R_2} = \frac{E_{R_2}}{R_2} = \frac{8}{2 \times 10^4} = \frac{8 \times 10^{-4}}{2}$$

$$= 4 \times 10^{-4} = .0004 \text{ ampere or } .4 \text{ mA.}$$

$$I_{R_3} = \frac{E_{R_3}}{R_3} = \frac{8}{8 \times 10^4} = \frac{8 \times 10^{-4}}{8}$$

$$= 1 \times 10^{-4} = .0001 \text{ ampere or } .1 \text{ mA.}$$

Notice that the total current flowing through R_2 and R_3 ($I_{R_2} + I_{R_3} = .4 \text{ mA} + .1 \text{ mA} = .5 \text{ mA}$) is equal to the current flowing through R_1 and R_4 (.5 mA). This is because R_2 and R_3 are in parallel with each other and in series with R_1 and R_4 . Since the same current flows at all points in a series circuit, a total of .5 mA must flow through the parallel branch of R_2 and R_3 .

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE
1022A

Example: A football is normally filled with
 A. ☒ A. air. B. sand. C. lead. D. water.
 B. ☐
 C. ☐
 D. ☐

1. A ☐ In a series circuit,
 B ☐ (A) the current through each component is different. (B) the total resistance is
 C ☐ found by the "product over the sum" formula. (C) the same voltage always appears
 D ☐ across each component. (D) there is only one path for current.
2. A ☐ What is the total resistance of a 50 k Ω , a 25 k Ω , and a 1 M Ω resistor connected in
 B ☐ series?
 C ☐ (A) 17.5 k Ω . (B) 1.075 M Ω . (C) 1.025 M Ω . (D) 100,750 ohms.
 D ☐
3. A ☐ If the TOTAL RESISTANCE in a series circuit DECREASES and the supply
 B ☐ voltage remains the same,
 C ☐ (A) circuit current increases. (B) the voltages across all components decrease.
 D ☐ (C) circuit current decreases. (D) circuit current remains the same.
4. A ☐ In a parallel circuit,
 B ☐ (A) the same current flows through each component. (B) the total resistance is
 C ☐ equal to the sum of the individual resistances. (C) only one current path exists.
 D ☐ (D) the sum of the branch currents equals the total current.
5. A ☐ What is the resistance of two 100 k Ω resistors connected in PARALLEL?
 B ☐ (A) 20 k Ω . (B) 25 k Ω . (C) 50 k Ω . (D) 125 k Ω .
 C ☐
 D ☐
6. A ☐ A parallel circuit consists of a 10 k Ω and a 30 k Ω resistor connected in parallel
 B ☐ with a 150-volt supply. What is the total circuit current?
 C ☐ (A) 5 mA. (B) 10 mA. (C) 20 mA. (D) 25 mA.
 D ☐
7. A ☐ When another branch is added to a PARALLEL circuit,
 B ☐ (A) the total current increases. (B) the total current decreases to one-half. (C) the
 C ☐ total resistance increases. (D) the current supplied to the complete circuit by the
 D ☐ source does not change.
8. A ☐ The circuit shown in Figure 21 is a
 B ☐ (A) series circuit. (B) short circuit. (C) combination of two series circuits con-
 C ☐ nected in parallel. (D) combination of two parallel circuits connected in series.
 D ☐
9. A ☐ What is the total resistance of the circuit of Figure 22 if R₂ is changed to 4 k Ω ?
 B ☐ (A) 11 k Ω . (B) 110 ohms. (C) 2.1 k Ω . (D) 990 ohms.
 C ☐
 D ☐
10. A ☐ If R₁ is INCREASED to 50 k Ω in Figure 24,
 B ☐ (A) the current through R₃ remains the same. (B) all of the source voltage now
 C ☐ appears across R₁. (C) the current through R₁ doubles. (D) the voltage across
 D ☐ R₃ doubles.

The first part of the report deals with the general situation of the country and the results of the survey.

The second part of the report deals with the results of the survey and the conclusions drawn from it.

The third part of the report deals with the results of the survey and the conclusions drawn from it.

The fourth part of the report deals with the results of the survey and the conclusions drawn from it.

The fifth part of the report deals with the results of the survey and the conclusions drawn from it.

The sixth part of the report deals with the results of the survey and the conclusions drawn from it.

The seventh part of the report deals with the results of the survey and the conclusions drawn from it.

The eighth part of the report deals with the results of the survey and the conclusions drawn from it.

The ninth part of the report deals with the results of the survey and the conclusions drawn from it.

The tenth part of the report deals with the results of the survey and the conclusions drawn from it.

The eleventh part of the report deals with the results of the survey and the conclusions drawn from it.

UNIT EXAMINATION FOR COURSE 104

This examination contains a number of different type questions: multiple choice, true or false, fill in the blank and direct question. To assist us in grading, please print your answers clearly on the answer sheet. **COMPLETE THE PORTION STATING YOUR NAME, ADDRESS AND STUDENT NUMBER ON THE ANSWER SHEET AND SEND ONLY THE ANSWER SHEET FOR GRADING.** Retain the examination questions for your records.

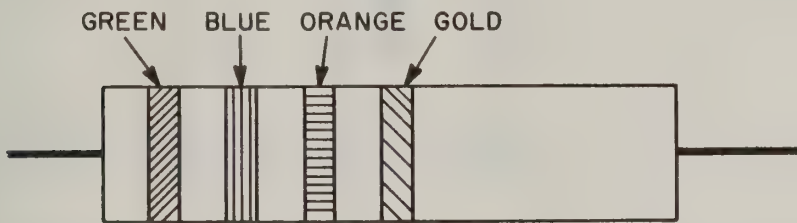


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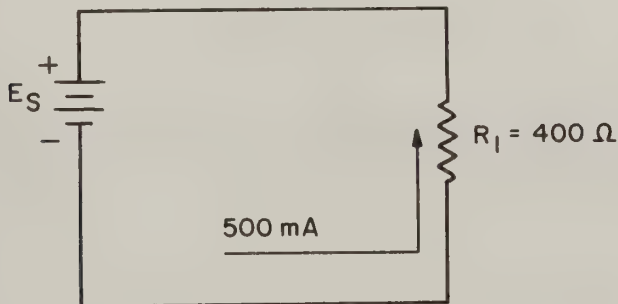
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1. An electron has a _____ charge.
2. In a complete electric circuit electrons flow from positive to negative.
True or False?
3. A conductor is a material that has _____ free electrons.
4. What is the value and tolerance of the resistor shown below? _____



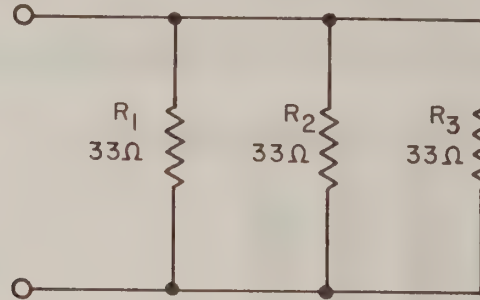
5. No. 20 wire has greater resistance per 1000 feet than No. 12 wire.
True or False?
6. The wattage rating of a carbon resistor depends mainly on its _____.
7. Which of the following is a correct form of Ohm's Law?
(A) $I = ER$. (B) $R = I/E$. (C) $I = R/E$. (D) $R = E/I$.
8. In an electric circuit, if the voltage is 150 volts and the resistance is 10 k Ω , the current is _____.
9. In the circuit shown below what is the value of the source voltage?



10. In a series circuit, the current is different in each component. True or False?

11. In a simple parallel circuit the source voltage appears across each component. True or False?

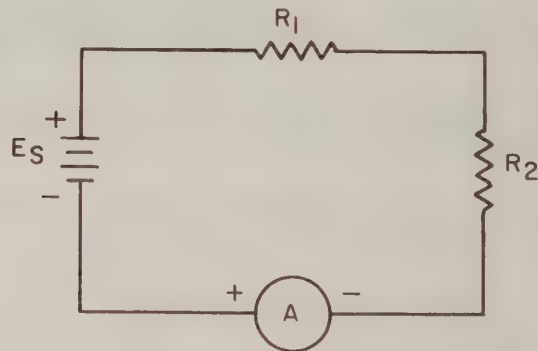
12. In the circuit shown below, what is the total circuit resistance? _____



13. The basic unit of measure of electric power is the _____.

14. A 10 ohm resistor is connected to a 20 volt dc source. How much power is dissipated by the resistor? _____

15. The ammeter is properly connected in the circuit shown below. True or False?

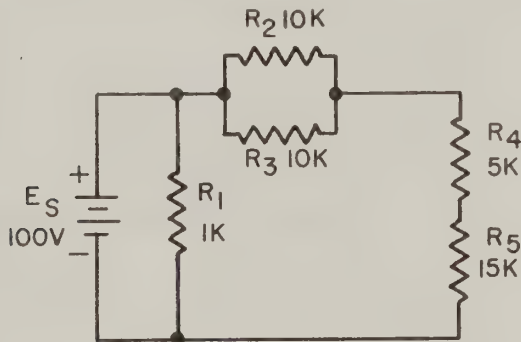


16. Is a dc voltmeter connected in series or parallel with the points where the voltage is to be measured? _____

17. What value of voltage is indicated on the meter scale shown below?
- _____



18. 4700 ohms expressed in scientific notation is _____.
19. If current and resistance are known and power must be found, the formula to use is _____.
20. In the circuit shown below, what is the voltage drop across R_4 ? _____



UNIT EXAMINATION 104 ANSWER SHEET

GRADE_____

INSTRUCTOR_____

Name_____

Student No._____

Address_____

UE104A

City_____

State/Province_____ Zip Code_____

Write your answers in the space provided. Be sure to include units, such as volts, μF , etc. where necessary.
RETURN ONLY THE ANSWER SHEET FOR GRADING. Keep the exam for your records.

1. _____

11. _____

2. _____

12. _____

3. _____

13. _____

4. _____

14. _____

5. _____

15. _____

6. _____

16. _____

7. _____

17. _____

8. _____

18. _____

9. _____

19. _____

10. _____

20. _____

NOTES

NOTES

NOTES



GUIDE SHEETS FOR EXPERIMENTS 9500 SERIES

INTRODUCTION TO ELECTRICITY AND ELECTRONICS

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MATERIALS

THIS LIST INCLUDES ALL TOOLS, HARDWARE AND ELECTRONIC COMPONENTS NEEDED TO COMPLETE THE EXPERIMENTS IN THIS MANUAL.

- | | |
|--|-------------------------------------|
| 3 - 1 k Ω , 1/2 W, 20% Resistors | 8 - Modular Connectors 5 ft. - Wire |
| 1 - 3.9 k Ω , 1/2 W, 20% Resistor | 1 - Basic Design Console with 2 |
| 1 - 4.7 k Ω , 1/2 W, 20% Resistor | Modular Panels |
| 2 - 10 k Ω , 1/2 W, 20% Resistors | 1 - 9 Volt Battery |
| 1 - 22 k Ω , 1/2 W, 20% Resistor | 1 - Battery Clip |
| 1 - 100 k Ω , 1/2 W, 20% Resistor | 1 - Multimeter and Test Leads |
| 1 - 220 k Ω , 1/2 W, 20% Resistor | 1 - AA Battery for Multimeter |
| 2 - 1 M Ω , 1/2 W, 20% Resistors | 2 - Test Prod Spring Adapters |
| 1 - 1 M Ω , Potentiometer | 3 - Alligator Clips |

INTRODUCTION

You are now starting what most students find the most interesting part of their training -- actually working with the circuits described in the lesson material. In the lab portion of your training, you will be working with the parts, circuits, and test equipment actually used in the electronics industry. The first piece of test equipment to be used is the multimeter. If you have not already done so, read the manual on using the meter. You will be expected to know how to read the scales in the first experiment. As you proceed, be sure to record all data as accurately and neatly as you can. Developing good practice from the beginning will help later as the experiments become more complex.

The list of materials includes resistors that have a tolerance of 20%. However, you may find that some of the resistors have instead a tolerance of only 10%.

Before connecting the battery in any experiment, check the circuit for short connections, because shorts can damage the battery. Also, be careful that there are no short circuits on the battery connector.

When performing the experiments, do not leave the battery connected to the circuit longer than necessary. Prolonged current drain weakens batteries.

EXPERIMENT I

BASIC CIRCUITS

PARTS NEEDED

- | | |
|---|-------------------------------|
| 1 - Basic Design Console with 2
Modular Panels | 2 - Test Prod Spring Adapters |
| 1 - 9 Volt Battery | 1 - Resistor (see text) |
| 1 - Battery Clip | 4 - Modular Connectors |
| 1 - Multimeter and Test Leads | Hookup Wire |

OBJECTIVE

The purpose of the first experiment is to familiarize you with the electro-lab system and establish the concept of source, circuit and load.

PROCEDURE

1. Select the battery and battery clip from your parts and snap the clip onto the battery.
2. Insert two modular connectors in the black modular design panel as shown, and insert the red wire from the battery into the upper connector (A) and the white lead into the other connector (B) as shown in Figure 1-1. You will notice there are spaces for four additional wires in each connector. Inserting a wire into any of these holes will connect that wire to the lead from the battery. The modular connector, then, allows us to set up a circuit, modify it or dismantle it in a very short period of time and without damaging the components. When working with the connectors, be sure to remove enough insulation from the connecting wires so that the wire slips into the connector all the way.
3. Cut two pieces of wire 2 1/2" long and remove about 1/2" of insulation from each end. Be careful not to nick the wire when removing the insulation.
4. Install two additional connectors (C and D) on the modular design panel and connect the four connectors as shown in Figure 1-2, with the wire prepared in Step 3.
5. Now, select a resistor from your parts (the small parts with bands of color on them), and insert the resistor into the connectors as shown in Figure 1-3. (Note, any of the resistors supplied will work in this experiment. You will learn more about these parts in your next lesson.)
6. Observe the circuit on the board and notice that you can trace the circuit from one terminal of the battery through the circuit to the resistor, through the resistor and back to the other battery terminal. Starting from the white lead of the battery, the path is as follows: through the wire to the modular connector

9500

1-1

(B); from the connector through the connecting wire to the next connector (D); through the resistor to the next connector (C); through the connecting wire, the last connector (A) and through the red wire to the other terminal of the battery. We have a complete circuit from the source (the battery) to the load (the resistor) by way of the connecting wires and in this case the modular connectors.

7. Set the switch of your multimeter to the proper range of the dc function to measure about 9 volts. Insert one test prod spring adapter into one of the three empty holes in connector C and the other into connector D. Insert the red test prod into the spring adapter in connector C and the black prod into the spring adapter in connector D. Figure 1-4 shows the side view of a spring adapter inserted into a connector with a test prod inserted into the spring adapter. Read the voltage obtained and record below.

_____volts

You should measure from 8 to 10 volts. If the voltage is less than 8, the battery is too weak and should be replaced.

8. While monitoring the voltage across the resistor, remove the wire connecting the two upper connectors (A and C). Record the voltage now measured.

_____volts

With the wire removed the circuit is now broken. There will be no voltage drop across the resistor because there is not a complete path for current. Reinsert the wire into the connector.

9. While again monitoring the voltage across the resistor, remove the wire connecting the two lower modular connectors (B and D). Record the voltage below.

_____volts

Again, the circuit has been broken, and there is not a complete path for current.

CONCLUSION

In this experiment we see that the circuit must be complete in order to obtain voltage across the resistor. A break anywhere in the circuit will disrupt electron flow, thus causing the circuit to be inoperative.

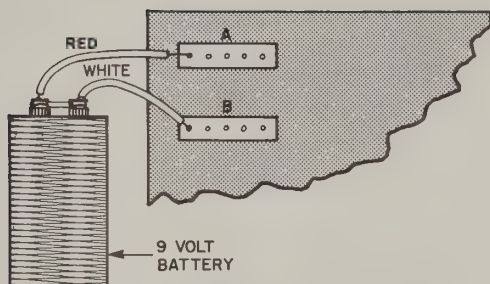


FIGURE 1-1

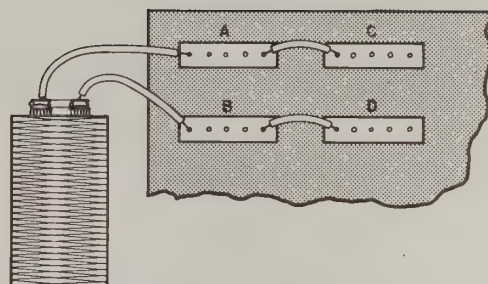


FIGURE 1-2

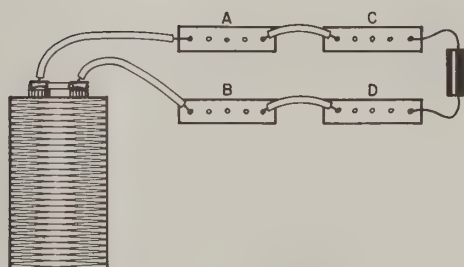


FIGURE 1-3



FIGURE 1-4

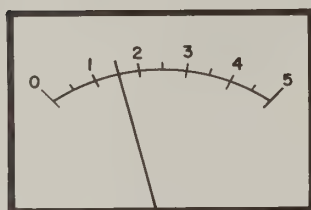


FIGURE 1-5

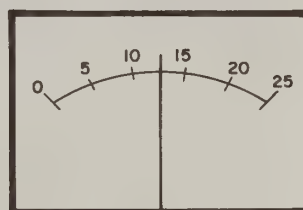


FIGURE 1-6

NOTES

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE
9500-1B

1. What are the necessary parts needed for a circuit to function properly?
 (A) Source and load. (B) Circuit, source and load. (C) Only a source. (D) Only a load.
 A ☐
 B ☐
 C ☐
 D ☐
2. In the circuit used in this experiment what would the voltage across the resistor be if one of the wires from the battery was broken?
 (A) 9 volts. (B) The battery voltage. (C) Zero volts. (D) 3 volts.
 A ☐
 B ☐
 C ☐
 D ☐
3. If you wished to place a switch in the circuit, where would the switch be placed?
 (A) Only between the negative terminal of the battery and the resistor. (B) Only between the positive terminal of the battery and the resistor. (C) Across the battery. (D) Anywhere in the circuit current path.
 A ☐
 B ☐
 C ☐
 D ☐
4. If you measured a voltage and the pointer deflected to the large mark between 1 and 2 as shown in Figure 1-5, what would the voltage be if the range switch was set to the 5 volt position?
 (A) 14 volts. (B) 5 volts. (C) 1.5 volts. (D) 7 volts.
 A ☐
 B ☐
 C ☐
 D ☐
5. If a voltage is measured which causes deflection to the large mark between 10 and 15 as shown in Figure 1-6, what is the voltage if the range switch is set to the 25 volt position?
 (A) 5 volts. (B) 12.5 volts. (C) 2.5 volts. (D) 25 volts.
 A ☐
 B ☐
 C ☐
 D ☐
6.
 A ☐
 B ☐
 C ☐
 D ☐
7.
 A ☐
 B ☐
 C ☐
 D ☐
8.
 A ☐
 B ☐
 C ☐
 D ☐
9.
 A ☐
 B ☐
 C ☐
 D ☐
10.
 A ☐
 B ☐
 C ☐
 D ☐

(THIS EXAM CONTAINS ONLY FIVE QUESTIONS)

EXPERIMENT 2

RESISTANCE

PARTS NEEDED

- | | |
|---|---------------------------------|
| 1 - Basic Design Console with 2
Modular Panels | 1 - Multimeter and Test Leads |
| 2 - Modular Connectors | 2 - Test Prod Spring Adapters |
| | 12 - Resistors (various values) |

OBJECTIVE

The purpose of this experiment is to learn to read the color code on resistors and to learn to use the ohms function of the multimeter.

PROCEDURE

1. Using Figure 9 on page 16 of lesson 1004, determine the color code of a 1 k Ω resistor. Find this resistor in your supply of parts. (Note: There may be a fifth color band on some of the resistors you have been sent. For our purposes this band can be ignored.)
2. Set the switch of your multimeter on the proper range of the ohms function. Short the two test prods and adjust the ohms adjust control so that the pointer is over zero. Insert two modular connectors alongside each other on the modular design panel as you did in Experiment 1. Insert one lead of the resistor in one modular connector and the other lead in the other connector. Then insert one test lead with its spring adapter into each of the modular connectors. The pointer deflection times the range switch setting should give a value of 1 k Ω .
3. Now set the range switch on the next higher range, touch the test leads together and again adjust the ohms adjust control. This control should be adjusted anytime the range switch is changed and should also be checked occasionally when measuring resistors on the same range. Following this procedure will insure the most accurate readings. Measure the 1 k Ω resistor by connecting the test prods across the resistor as you did in Step 2. The deflection multiplied by the range switch setting results in a final resistance value of 1 k Ω .

The resistor can be measured on more than one range of the ohms function, but the accuracy of the measurements will not be the same. The most accurate reading will be obtained when the deflection is closest to mid-scale. Anytime resistance measurements are made, choose the range which produces deflection closest to mid-scale. Along with the accuracy of the meter, the tolerance of the resistors will vary the readings you obtain. Allow about a 20% variation in all of your measurements. For higher values of resistors the error may go even higher because of the small amount of deflection obtained.

4. Measure all the resistors supplied and fill out the chart below.

Resistance

Color Coded Value	Measured Value
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms
_____ ohms	_____ ohms

CONCLUSION

The important points to note in this experiment are: Carefully set the ohms adjust control before making measurements; to insure accurate values use the range switch setting which produces a deflection closest to mid-scale; and allow variations in your measurements due to the tolerance of the resistors and of the multimeter.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

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Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

9500-2A

1. Which would be the best range switch setting to use when measuring a 10 k Ω resistor?
 (A) $\times 1K$. (B) $\times 10$.
 A ☐
 B ☐
 C ☐
 D ☐
2. The color code of a resistor is red-red-orange. What is its value?
 (A) 2.2 k Ω . (B) 220 k Ω . (C) 3.2 k Ω . (D) 22 k Ω .
 A ☐
 B ☐
 C ☐
 D ☐
3. When measuring a resistor, the pointer deflects to the 100 mark. What is the value of the resistor if the range switch is on the $\times 1K$ range?
 (A) 100 Ω . (B) 1 k Ω . (C) 10 k Ω . (D) 100 k Ω .
 A ☐
 B ☐
 C ☐
 D ☐
4. If a high value resistor with a 20% tolerance is measured and the value measured is 25% from the coded value, is the component out of tolerance?
 (A) The component may be out of tolerance depending on the accuracy of the measuring device.
 (B) The component is out of tolerance. (C) The component is definitely not out of tolerance.
 (A) Full scale. (B) Mid-scale. (C) 2/3 full scale. (D) 1/3 full scale.
 A ☐
 B ☐
 C ☐
 D ☐
5. Where are the most accurate readings obtained when using the ohmmeter?
 (A) Full scale. (B) Mid-scale. (C) 2/3 full scale. (D) 1/3 full scale.
 A ☐
 B ☐
 C ☐
 D ☐
6.
 A ☐
 B ☐
 C ☐
 D ☐
7. (THIS EXAM CONTAINS ONLY FIVE QUESTIONS)
 A ☐
 B ☐
 C ☐
 D ☐
8.
 A ☐
 B ☐
 C ☐
 D ☐
9.
 A ☐
 B ☐
 C ☐
 D ☐
10.
 A ☐
 B ☐
 C ☐
 D ☐

EXPERIMENT 3

OHM'S LAW

PARTS NEEDED

- | | |
|---|---------------------------------------|
| 1 - Basic Design Console with 2
Modular Panels | 2 - Test Prod Spring Adapters |
| 1 - 10 k Ω , 1/2 W, 20% Resistor | 1 - 9 Volt Battery with Clip |
| 1 - 22 k Ω , 1/2 W, 20% Resistor | Modular Connectors and Hookup
Wire |
| 1 - 4.7 k Ω , 1/2 W, 20% Resistor | 1 - Multimeter and Test Leads |
| 1 - 220 k Ω , 1/2 W, 20% Resistor | |

OBJECTIVE

The purpose of this experiment is to demonstrate the concept of Ohm's Law, to prove its validity and to show the relationship between a schematic diagram and an actual circuit.

PROCEDURE

1. Set up the circuit shown in Figure 3-1. This is the same circuit used in Experiment 1 except that we now have a specific value resistor in the circuit. Figure 3-2 shows the schematic diagram of the circuit. You will notice that the schematic diagram does not show the wires between the modular connectors A and B and between C and D. The schematic only shows the electrical connections but does not show the physical layout of the circuit. Electrically, the two diagrams show the same thing.

2. Measure the voltage across the resistor. Record your value below.

_____ volts

3. Using the value of voltage measured and the coded value of the resistor, calculate the value of current in the circuit using Ohm's Law. Record your current value below.

_____ mA, calculated

Using the rated value of the battery (9 volts) as an example, your calculation should be similar to that below:

9500

3-1

$$I = \frac{E}{R}$$

$$I = \frac{9 \text{ volts}}{10 \text{ k}\Omega}$$

$$I = \frac{9 \text{ volts}}{10,000 \text{ ohms}}$$

$$I = .0009\text{A}$$

$$I = .9 \text{ mA}$$

4. Insert a test prod spring adapter into each of the upper modular connectors, and insert the red test prod into the left connector. Insert the black test prod into the right connector. Set the multimeter to the proper range of the ammeter function. Remove the jumper wire A between the two connectors. You are now measuring the current in the circuit. Record the value measured below.

_____ mA

Compare the measured value with the value calculated above. The two values should be similar. Exact agreement probably will not be obtained, due to the tolerance of the resistor and the accuracy of the meter. For example, if you measure 8.5V across the battery, your current value may be as low as .75 mA.

5. Select a 22 k Ω resistor and insert this component instead of the 10 k Ω resistor. This circuit is shown schematically in Figure 3-3. Measure the circuit current in the same manner as above. Record your value below.

_____ mA

Your measurement should be lower than the value in Step 4 since there is more resistance in the circuit. A 22 k Ω resistor is about twice the value of a 10 k Ω resistor so your current measurement should be about half the value in Step 4.

6. Remove the 22 k Ω resistor and insert a 4.7 k Ω resistor in the circuit. Since the resistance has been decreased, the current should increase. The 4.7 k Ω resistor is about half the value of the 10 k Ω resistor so the current should now be about twice the value obtained in Step 4.

7. Substitute the 220 k Ω resistor for the 4.7 k Ω resistor used in Step 6. Measure the circuit current and record your value below.

_____ mA

Ohm's Law

From Ohm's Law the current in this circuit is:

$$I = \frac{E}{R}$$

$$I = \frac{9V}{220,000\Omega}$$

$$I = .00004 \text{ amps. (approx.)}$$

$$I = 40 \mu A$$

The measured current then should be close to 40 μA . To measure this current, the proper range should be used. The next higher range will provide very little deflection and thus an inaccurate measurement.

CONCLUSION

In this experiment we see that Ohm's Law can be used to determine the value of current in a circuit. Direct measurement will verify the calculated values, allowing for meter error and component tolerance. Also, the schematic diagram shows only the electrical connections of a circuit, not the actual parts layout.

NOTES

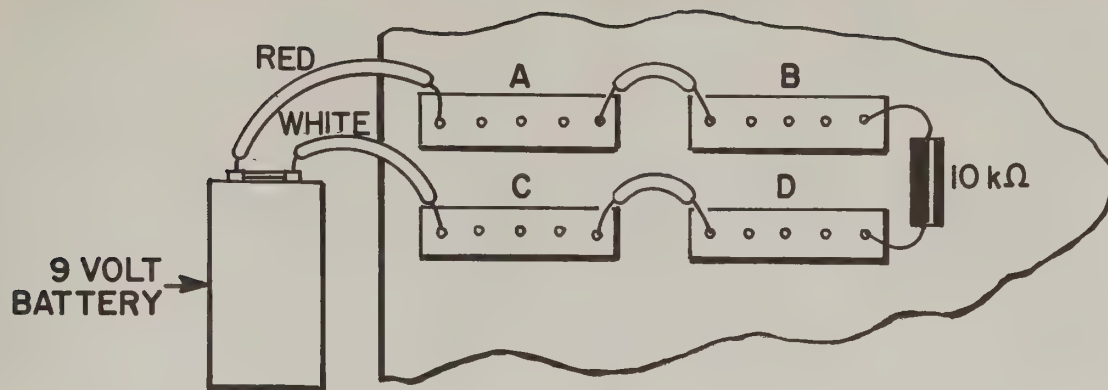


FIGURE 3-1

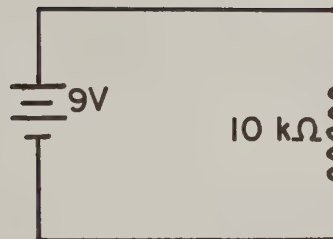


FIGURE 3-2

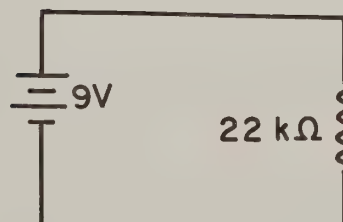


FIGURE 3-3

NOTES

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

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LESSON CODE

9500-3A

1. If the resistance in a circuit is decreased while the voltage remains constant, what happens to the current?
A ☐
B ☐
C ☐
D ☐
(A) Increases. (B) Decreases. (C) Remains the same.
2. If the resistance in a circuit is increased while the voltage remains constant, what happens to the current?
A ☐
B ☐
C ☐
D ☐
(A) Increases. (B) Decreases. (C) Remains the same.
3. A schematic diagram shows the _____ layout of a circuit.
A ☐
B ☐
C ☐
D ☐
(A) electrical (B) physical
4. If the rated battery voltage in a circuit is 10 volts and the resistance is 10 k Ω , what is the circuit current?
A ☐
B ☐
C ☐
D ☐
(A) 1 mA. (B) 10 mA. (C) 10A. (D) 5 mA.
5. In the circuit described in Question 4, if the measured current is low by 10%, what could be the reason?
A ☐
B ☐
C ☐
D ☐
(A) Meter error. (B) Source less than rated voltage. (C) Resistance higher than rated.
(D) Any of the above.
6.
A ☐
B ☐
C ☐
D ☐
7. (THIS EXAM CONTAINS ONLY FIVE QUESTIONS)
A ☐
B ☐
C ☐
D ☐
8.
A ☐
B ☐
C ☐
D ☐
9.
A ☐
B ☐
C ☐
D ☐
10.
A ☐
B ☐
C ☐
D ☐

EXPERIMENT 4

REFERENCE POINTS—SERIES AND PARALLEL CIRCUITS

PARTS NEEDED

- | | |
|---|---|
| 1 - Basic Design Console with 2
Modular Panels | 1 - 22 k Ω , 1/2 W, 20% Resistor |
| 3 - 1 k Ω , 1/2 W, 20% Resistors | 1 - 9 Volt Battery with Clip |
| 1 - 3.9 k Ω , 1/2 W, 20% Resistor | Modular Connectors and Hookup
Wire |
| 1 - 4.7 k Ω , 1/2 W, 20% Resistor | 1 - Multimeter and Test Leads |
| 1 - 10 k Ω , 1/2 W, 20% Resistor | 2 - Test Prod Spring Adapters |

OBJECTIVE

The purpose of the following experiment is to investigate the concept of ground and to demonstrate the rules of series and parallel circuits.

PART 1

PROCEDURE

1. Set up the circuit shown in Figure 4-1. The schematic diagram is shown in Figure 4-2.

2. Set the switch of your multimeter on the proper range of the dc function. Place the black test prod of your multimeter at point D in the circuit and the red test prod at point C. Record the voltage measured below. You should measure about one third of the total source voltage.

_____ volts

3. Move the red test prod to point B and again measure the voltage. Record your measurement below. Since you are now measuring across two resistors, your measured value should be about two thirds of the source voltage or twice the voltage measured in Step 2. Try to develop the habit of estimating the voltage expected at a point before making the measurement. Following this procedure will help to choose the proper range switch setting.

_____ volts

4. Move the red test prod to point A in the circuit. Record your measurement below.

_____ volts

In the above series of measurements, the black test prod has not been moved. All measurements were taken with respect to the same point. In this case, then, point D is the reference point (or ground) of the circuit. The voltage at point C is about 3 volts with respect to point D, point B is about 6 volts with respect to

Reference Points - Series And Parallel Circuits

point D, and point A is about 9 volts with respect to point D. Ground, then, simply indicates the reference point to which all measurements are taken. Point D as ground is shown in Figure 4-3.

5. Move the black test prod to point C in the circuit. Measure the voltage at point B with respect to point C by connecting the red test prod to point B. Record the voltage below.

_____ volts

Since the voltage being measured is across only one resistor, the value should be about 3 volts. We have now changed the reference point and point C is now ground. Figure 4-4 shows point C as ground.

6. Measure the voltage at point A with respect to point C. Record the voltage below.

_____ volts

Since the voltage being measured is now across two resistors, the measured value should be about 6 volts.

7. Leave the black test prod at point C and very briefly touch the red test prod to point D. The pointer now deflects to the left which indicates the voltage at point D is negative with respect to point C. To measure this voltage the test prods must be reversed; that is, the black prod must be on point D and the red prod on point C. The voltage can then be measured but must be shown as a negative voltage since we are measuring at point D with respect to point C. The color of the test prod from the multimeter does not determine the reference point. The reference point in ground is a function of the circuit, not the test instrument. The voltage at point D with respect to point C is then about -3 volts. Record the actual voltage below.

_____ volts

CONCLUSION

In this experiment we see that the voltage measured in a circuit depends on a reference point. Different measurements can be obtained by simply changing the reference point (or ground). The ground point is dependent upon the circuit and not the measuring device. While the black test prod is generally placed on ground, this procedure cannot always be followed as seen in Step 7. In cases such as Step 7 the test prods are reversed, but the final measurement is shown as a negative voltage.

Reference Points - Series And Parallel Circuits

PART 2

PROCEDURE

1. Set up the circuit shown in Figure 4-5. Use a layout similar to Figure 1. By using this layout, either of the jumper wires can be removed and the multi-meter installed in the place of the wire to measure current. The same procedure was followed in Experiment 3. Anytime current is to be measured, the above procedure will simplify the measurement.

2. Using the measured resistance and the measured battery voltage, calculate the circuit current. Record your calculated value below.

_____ mA

Your calculations should be similar to those below where the rated values of the parts are used:

$$I = \frac{E}{R_T}$$

$$R_T = R_1 + R_2$$

$$R_T = 4.7 \text{ k}\Omega + 3.9 \text{ k}\Omega$$

$$R_T = 4700 + 3900$$

$$R_T = 8600\Omega$$

$$I = \frac{9V}{8600\Omega}$$

$$I = 1.04 \text{ mA.}$$

3. Using the proper range switch setting, measure the current in the circuit by placing the multimeter between the red battery lead and the resistors. Record the value below. The measured value should correspond to the calculated value.

_____ mA

Reference Points - Series And Parallel Circuits

4. Using the same procedure, remeasure the current in the circuit by placing the multimeter between the white battery lead and the resistors. Record your measurement below.

_____ mA

The values measured in Steps 3 and 4 should be the same since the current in a series circuit is the same throughout the circuit.

5. Using the measured values of resistance and the measured current value as found in Step 3, calculate the voltage expected across each resistor. Record your values below.

E_{R_1} _____ volts

E_{R_2} _____ volts

Using the rated values of the parts and the calculated current, your calculations should look as below;

$$E_{R_1} = IR_1$$

$$E_{R_2} = IR_2$$

$$E_{R_1} = (1.04 \text{ mA})(4.7 \text{ k}\Omega)$$

$$E_{R_2} = (1.04 \text{ mA})(3.9 \text{ k}\Omega)$$

$$E_{R_1} = (0.00104)(4700)$$

$$E_{R_2} = (0.00104)(3900)$$

$$E_{R_1} = 4.89 \text{ volts}$$

$$E_{R_2} = 4.06 \text{ volts}$$

6. Using the proper range switch setting, measure the voltage across the 4.7 k Ω resistor. Record your measurement below.

_____ volts

7. Measure the voltage across the 3.9 k Ω resistor and record your measurement below.

_____ volts

8. Measure the total voltage across the two resistors and record your measurement.

_____ volts

The sum of the voltages recorded in Steps 6 and 7 should correspond with the voltage measured in Step 8. Add the two voltages and compare the result with Step 8.

Reference Points - Series And Parallel Circuits

9. Disconnect the battery and measure the resistance of the circuit by placing the test prods across both resistors. Be sure to adjust the ohms adjust control before measuring the resistance. Record the value obtained below.

_____ ohms

The total resistance should correspond with the sum of the resistance of the individual resistors. Measure the individual resistors and add their values. The sum should be about equal to that measured above.

CONCLUSION

In this series of experiments, you have proven the three laws of series circuits. The current is the same at all points of a series circuit. The sum of the voltages across the individual components is equal to the source voltage, and the total resistance is equal to the sum of the individual resistors.

PART 3

PROCEDURE

1. Set up the circuit shown in Figure 4-6. A suggested layout is shown in Figure 4-7. Using this layout will allow current measurement in the circuit with little difficulty.

2. Measure the voltage across the battery and also the voltage across the two resistors. Record the values below. The voltages should all be the same.

E_{R_1} _____ volts

E_{R_2} _____ volts

$E_{BATTERY}$ _____ volts

3. Using the current function and the proper setting of the range switch, measure the current through the 10 k Ω resistor, R_1 , by removing the jumper at point B and inserting the multimeter. Record your measurement below.

I_{R_1} _____ mA

4. Measure the current through the 22 k Ω resistor by removing the wire at point C and inserting the multimeter. Record your measurement below.

I_{R_2} _____ mA

5. Measure the total current by removing the jumper wire at point A and inserting the multimeter. Record your measurement below.

I_T _____ mA

Reference Points - Series And Parallel Circuits

The sum of the values found in Steps 3 and 4 should equal the value found in Step 5. Add your measurement and compare the result to the value found in Step 5.

6. Disconnect the battery terminals and connect the ohmmeter to the same points to which the battery was connected. Be sure to adjust the ohms adjust control before measuring the resistance. You will be measuring the total resistance in the circuit. Record your result below.

R_T _____ ohms

The total resistance measured should be less than the resistance of either of the two resistors in the circuit. We can calculate the total resistance by using Ohm's Law. The total voltage divided by the total current will give the total resistance.

Using the total current found in Step 5 and the total voltage found in Step 2, calculate the total resistance. Record the value below. Compare the total resistance measured with the total calculated. The two values should compare closely.

R_T _____ ohms

CONCLUSION

In this part we have verified the three rules of parallel circuits. The voltage across each component in a simple parallel circuit is the same; the total current is equal to the sum of the branch currents; and the total resistance is less than any of the branch resistors.

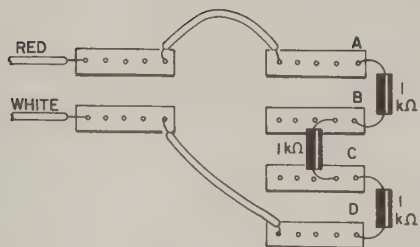


FIGURE 4-1

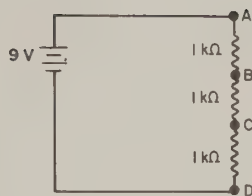


FIGURE 4-2

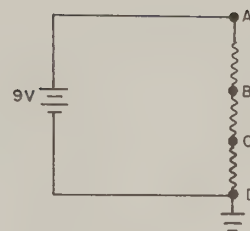


FIGURE 4-3

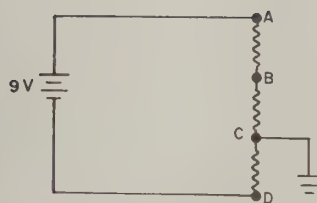


FIGURE 4-4

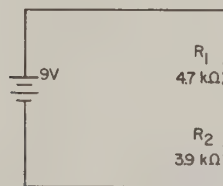


FIGURE 4-5



FIGURE 4-6

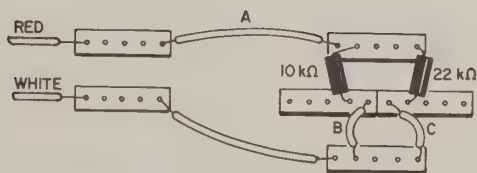


FIGURE 4-7

NOTES

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

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LESSON CODE
9500-4A

1. In the circuit of Figure 4-2, what is the voltage at point C with respect to point B if there are 3 volts across each resistor?
 A ☐ (A) -3 volts. (B) 6 volts. (C) +3 volts. (D) -6 volts.
 B ☐
 C ☐
 D ☐
2. In Figure 4-4 what is the voltage at point A with respect to ground, assuming 3 volts across each resistor?
 A ☐ (A) -6 volts. (B) 9 volts. (C) 6 volts. (D) 3 volts.
 B ☐
 C ☐
 D ☐
3. In the circuit of Figure 4-5, if a current meter was placed between the two resistors, the current measured would be:
 A ☐ (A) less than the current measured between the battery and R_1 . (B) greater than the current
 B ☐ measured between the battery and R_2 . (C) the same as the current measured at any other
 C ☐ point in the circuit. (D) less than the current measured between the battery and R_2 .
 D ☐
4. If the resistors in Figure 4-5 were changed to $R_1 = 10\text{ k}\Omega$ and $R_2 = 22\text{ k}\Omega$, what would be the total resistance?
 A ☐ (A) Less than either of the values in the circuit. (B) $32\text{ k}\Omega$. (C) $12\text{ k}\Omega$. (D) $8\text{ k}\Omega$.
 B ☐
 C ☐
 D ☐
5. What would be the total voltage in a circuit similar to Figure 4-5 if the voltage across R_1 is 12 volts and the voltage across R_2 is 24 volts?
 A ☐ (A) 36 volts. (B) 12 volts. (C) 24 volts. (D) 10 volts.
 B ☐
 C ☐
 D ☐
6. If the resistors of Figure 4-6 are both $10\text{ k}\Omega$ each and the source voltage is 10 volts, what is the total resistance?
 A ☐ (A) $10\text{ k}\Omega$. (B) $5\text{ k}\Omega$. (C) $20\text{ k}\Omega$. (D) $18\text{ k}\Omega$.
 B ☐
 C ☐
 D ☐
7. If R_1 in the circuit of Figure 4-6 is increased, the total current will
 A ☐ (A) increase. (B) decrease. (C) remain the same.
 B ☐
 C ☐
 D ☐
8. If R_1 in the circuit of Figure 4-6 is decreased, the total voltage will
 A ☐ (A) increase. (B) decrease. (C) remain the same.
 B ☐
 C ☐
 D ☐
9. If another branch is added to the circuit of Figure 4-6, the total current will
 A ☐ (A) increase. (B) decrease.
 B ☐
 C ☐
 D ☐
10. In Figure 4-6 what is the current through the $10\text{ k}\Omega$ resistor if the source voltage is 9 volts?
 A ☐ (A) 90 mA. (B) 1.1 mA. (C) 11 mA. (D) .9 mA.
 B ☐
 C ☐
 D ☐

9
10

EXPERIMENT 5

POWER CALCULATIONS AND MEASUREMENTS

PARTS NEEDED

- | | |
|---|---------------------------------------|
| 1 - Basic Design Console with 2
Modular Panels | 1 - Battery with Clip |
| 1 - 1 k Ω , 1/2 W, 20% Resistor | Modular Connectors and Hookup
Wire |
| 1 - 4.7 k Ω , 1/2 W, 20% Resistor | 1 - Multimeter and Test Leads |
| 2 - 10 k Ω , 1/2 W, 20% Resistor | 2 - Test Prod Spring Adapters |

OBJECTIVE

The purpose of this experiment is to investigate the power dissipated in a circuit and develop methods of measuring power.

PART 1

PROCEDURE

1. Set up the circuit shown in Figure 5-1. Be sure to allow for the measurement of current in your layout.

2. Measure the current in the circuit and record your measurement below.

I_T _____ mA

3. Measure the voltage of the battery. Using this value of voltage and the current measured in Step 2, calculate the power dissipated on the circuit. Use the formula $P = EI$. Record both the battery voltage and the calculated power below.

E_{BATT} _____ volts

P _____ mW

4. Measure the voltage across both R_1 and R_2 . Record the voltages below.

E_{R_1} _____ volts

E_{R_2} _____ volts

5. Using the measured current found in Step 2 and the voltages in Step 4,

9500

5-1

Power Calculations And Measurements

calculate the power dissipated by each resistor.

P_{R_1} _____ mW

P_{R_2} _____ mW

In a circuit, the total power dissipated is equal to the sum of the power dissipated by each component. In Step 3 the total power in the circuit was determined. In Step 5 the power dissipated by each resistor was determined. Add the values found in Step 5 and compare the sum with the total power. The two values should correspond.

PART 2

PROCEDURE

1. Set up the circuit shown in Figure 5-2. Again, be sure to allow for current measurements in each branch as well as total current.

2. Measure the total current in the circuit and record your result below.

I_T _____ mA

3. Measure the battery voltage. Use this value and the current found in Step 2 to calculate the total power. Record the battery voltage and the calculated power.

E_{BATT} _____ volts

P_T _____ mW

4. Measure the current through R_1 and also through R_2 . Using these current measurements and the battery voltage, calculate the power dissipated by each resistor. Record the results below.

I_{R_1} _____ mA

I_{R_2} _____ mA

P_{R_1} _____ mW

P_{R_2} _____ mW

As in the series circuit investigated in part one, the total power in a circuit is equal to the sum of the power dissipated by each component. The sum of the

Power Calculations And Measurements

power calculated in Step 4 should be equal to the total power calculated in Step 3.

CONCLUSION

In these experiments we see that the total power in a series or parallel circuit is equal to the sum of the power dissipated by the individual components.

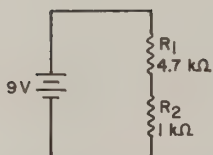


FIGURE 5-1



FIGURE 5-2

NOTES

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question.

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LESSON CODE
9500-5A

1. What is the power dissipated by a resistor if the voltage across it is 10 volts and the current through it is 1 mA?
 (A) 10 watts. (B) .01 watt. (C) .1 watt. (D) 1 mW.

A ☐

B ☐

C ☐

D ☐
2. If the current in a circuit increases, the power dissipated will:
 (A) increase. (B) decrease. (C) remain the same.

A ☐

B ☐

C ☐

D ☐
3. In a series circuit consisting of three resistors, what is the total power dissipated if the resistors each dissipate 3 watts of power?
 (A) 3 watts. (B) 6 watts. (C) 9 watts. (D) 10 watts.

A ☐

B ☐

C ☐

D ☐
4. In the circuit of Figure 5-2 what is the power dissipated by R₂?
 (A) .008 watt. (B) .9 watt. (C) 90 mW. (D) .8 watt.

A ☐

B ☐

C ☐

D ☐
5. In a parallel circuit consisting of two resistors, what is the total power if one resistor dissipates 5 watts and the other 6 watts?
 (A) 1 watt. (B) 11 watts. (C) 30 watts. (D) 10 watts.

A ☐

B ☐

C ☐

D ☐
6.

A ☐

B ☐

C ☐

D ☐
7.

A ☐

B ☐

C ☐

D ☐
8.

A ☐

B ☐

C ☐

D ☐
9.

A ☐

B ☐

C ☐

D ☐
10.

A ☐

B ☐

C ☐

D ☐

(THIS EXAM CONTAINS ONLY FIVE QUESTIONS)

EXPERIMENT 6

LOADING EFFECTS OF METERS

PARTS NEEDED

- 1 - Basic Design Console with 2
Modular Panels
- 2 - 1 M Ω , 1/2 W, 20% Resistors
- 1 - Battery with Clip

- Modular Connectors and Hookup
Wire
- 1 - Multimeter and Test Leads
- 2 - Test Prod Spring Adapters

OBJECTIVE

The purpose of this experiment is to demonstrate the measurement error introduced when using a voltmeter.

PROCEDURE

1. Set up the circuit shown in Figure 6-1. Using Ohm's Law, calculate the voltage across each resistor. Use the rated value of the resistors and the measured battery voltage.

E_{R_1} _____ volts, calculated

E_{R_2} _____ volts, calculated

Your calculations should be similar to those below where the rated source voltage and rated resistor values are used:

$$R_T = R_1 + R_2$$

$$R_T = 1M + 1M$$

$$R_T = 2M$$

$$I_T = \frac{E_T}{R_T}$$

$$= \frac{9V}{2M\Omega}$$

$$I_T = 4.5 \mu A$$

$$E_{R_1} = I_{R_1} \cdot R_1$$

$$= 4.5 \mu A \cdot 1 M\Omega$$

$$= 4.5 \text{ volts}$$

$$E_{R_2} = I_{R_2} \cdot R_2$$

$$= 4.5 \mu A \cdot 1 M\Omega$$

$$= 4.5 \text{ volts.}$$

Loading Effects Of Meters

2. Measure the voltage across both the resistors using the proper range. Record the results below.

E_{R_1} _____ volts, measured

E_{R_2} _____ volts, measured

3. Measure the voltage across both resistors again but use the next higher range. Record your results below.

E_{R_1} _____ volts, measured

E_{R_2} _____ volts, measured

4. Again measure the voltage across both resistors but use the next higher range. Record the results below.

E_{R_1} _____ volts

E_{R_2} _____ volts

The input sensitivity of the voltmeter is 20 k Ω /volt. This means the actual resistance the meter presents to a circuit under test will vary, depending on the setting of the range switch. To determine the actual resistance of the voltmeter, simply multiply the range switch setting by 20 k Ω .

Because of the low resistance, the meter will greatly affect the measurement in a high resistance circuit such as the one used in this experiment. The actual circuit is as shown in Figure 6-2. The meter disrupts the circuit so that an accurate measurement is impossible. As the range switch setting is changed, the measurement becomes more accurate but still does not give a true measurement. To reduce the problem, a meter with a high input resistance must be used, and this meter must be used in low resistance circuits only.

One example of the effects of meter loading is that a meter of 1000 Ω per volt can introduce an error as high as 33% when the resistor being measured for voltage drop is 500 Ω . Another example is when the resistor being measured for voltage drop is 1000 Ω and the meter has a resistance of 10 k Ω per volt, then the error can be 9% maximum. Consequently, when the meter resistance is twice the value of the resistor being measured, the error is 33% maximum; and when the meter resistance is 10 times that of the measured resistor, the error is 9% at the most. How much the error actually is depends upon the circuit containing the resistor being measured for voltage drop.

Loading Effects Of Meters

CONCLUSION

In all cases a circuit will be affected to some degree by connecting a measuring device. In the case of a voltmeter, the resistance presented to a circuit must be as high as possible to prevent inaccurate measurements. For an error under 10%, the meter resistance must be at least 10 times the resistance of the resistor being measured for voltage drop.

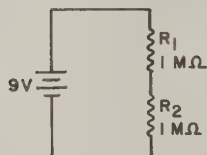


FIGURE 6-1

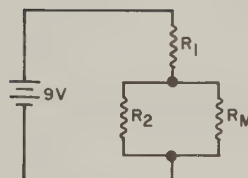


FIGURE 6-2

NOTES

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

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LESSON CODE

9500-6A

1. If a meter has a sensitivity of $1000\Omega/V$, what resistance does the meter present if the range switch is placed on the **10** volt range?
 (A) ☐ 1,000,000 Ω . (B) ☐ 100 Ω . (C) ☒ 10,000 Ω . (D) ☐ 1000 Ω .
2. If a meter has a sensitivity of $1000\Omega/V$ and another meter has a sensitivity of $20,000\Omega/V$, which would have the least effect on a circuit under test?
 (A) ☐ The meter with a sensitivity of $1000\Omega/V$. (B) ☒ The meter with a sensitivity of $20,000\Omega/V$.
3. If a meter with a sensitivity of $20,000\Omega/V$ is used to measure the voltage across a 10Ω resistor, would you expect a large error due to loading effects?
 (A) ☐ Yes. (B) ☒ No.
4. In the situation described in Question 3, would you expect a large error due to loading effects if the input sensitivity of the meter is $1000\Omega/V$?
 (A) ☐ Yes. (B) ☒ No.
5. To prevent error due to loading effects should a voltmeter have a high resistance or a low resistance?
 (A) ☐ Low. (B) ☒ High.
6.

A ☐
 B ☐
 C ☐
 D ☐
7. (THIS EXAM CONTAINS ONLY FIVE QUESTIONS)

A ☐
 B ☐
 C ☐
 D ☐
8.

A ☐
 B ☐
 C ☐
 D ☐
9.

A ☐
 B ☐
 C ☐
 D ☐
10.

A ☐
 B ☐
 C ☐
 D ☐

EXPERIMENT 7

OHM'S LAW-ADVANCED CIRCUITS

PARTS NEEDED

- | | |
|--|---------------------------------------|
| 1 - Basic Design Console with 2
Modular Panels. | 1 - 9V Battery with Clip |
| 1 - 3.9 k Ω , 1/2 W, 20% Resistor | Modular Connectors and Hookup
Wire |
| 1 - 4.7 k Ω , 1/2 W, 20% Resistor | 1 - Multimeter and Test Prods |
| 2 - 10 k Ω , 1/2 W, 20% Resistors | 2 - Test Prod Spring Adapters |
| 1 - 22 k Ω , 1/2 W, 20% Resistor | |

OBJECTIVE

The purpose of this experiment is to further investigate circuits using Ohm's Law and to practice solving problems with scientific notation.

PART 1

PROCEDURE

1. Set up the circuit shown in Figure 7-1. The schematic diagram for this circuit is shown in Figure 7-2.
2. Using measured resistances and measured source voltage, calculate the total current in the circuit. Record your result below.

_____ mA

Your calculations should appear similar to those below where the rated values of the parts are used:

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 10 \text{ k}\Omega + 4.7 \text{ k}\Omega + 3.9 \text{ k}\Omega$$

$$R_T = 10 \times 10^3 + 4.7 \times 10^3 + 3.9 \times 10^3 = 18.6 \times 10^3 = 18.6 \text{ k}\Omega$$

$$I_T = \frac{E}{R_T}$$

$$I_T = \frac{9 \text{ volts}}{18.6 \times 10^3 \Omega}$$

$$I_T = .48 \times 10^{-3}$$

$$I_T = .48 \text{ mA}$$

3. Measure the total current to verify your calculations. Record the value below.

_____ mA

4. Install the multimeter in the circuit in place of the jumper wire between the two upper connectors (between D and E). Monitor the total current in the circuit and move the lower wire from point A to point B. Record the new circuit current below.

_____ mA

5. While still monitoring the current, move the lower wire from point B to point C. Record the new current below.

_____ mA

In each step the total resistance has been reduced. Since the source voltage has not changed, the current must increase due to the decrease in resistance.

6. Connect the voltmeter across the 10 k Ω resistor (R_1) using the proper range. Reconnect the jumper between the two upper connectors (D and E) and move the lower wire from C back to point A. Record the voltage across R_1 below.

_____ volts

7. Move the lower wire from point A to point B while monitoring the voltage across R_1 . Record the new voltage below.

_____ volts

8. Again move the lower wire from point B to point C. Record your measurement below.

_____ volts

9500

7-2

Ohm's Law - Advanced Circuits

As we saw in Steps 3, 4 and 5 the current in the circuit is increasing each time the wire is moved. When measuring across the 10 k Ω resistor, the voltage must increase as the wire is moved since the current is increasing and the resistance across which the measurement takes is constant.

CONCLUSION

In this part of the experiment we see that current is inversely proportional to resistance and voltage drop is directly proportional to current.

PART 2

PROCEDURE

1. Set up the circuit shown in Figure 7-3. Figure 7-4 shows the schematic diagram of the circuit.
2. Measure the total current in the circuit by removing jumper wire A and installing the multimeter in its place. Calculate the total current using measured values and record the measured and calculated values below.

I_T _____ mA, measured

I_T _____ mA, calculated

Your calculated values should be similar to those below where rated values are used. Remember the problems can be worked more than one way and the work below is not the only way to proceed. The results should be the same, however.

$$I_{R1} = \frac{E_T}{R_1} = \frac{9V}{10 \times 10^3} = .9 \times 10^{-3} = .9 \text{ mA}$$

$$I_{R2} = \frac{E_T}{R_2} = \frac{9V}{22 \times 10^3} = .4 \times 10^{-3} \text{ (approx.)}$$

$$I_{R3} = \frac{E_T}{R_3} = \frac{9V}{10 \times 10^3} = .9 \times 10^{-3} = .9 \text{ mA}$$

$$I_T = I_{R1} + I_{R2} + I_{R3}$$

$$I_T = .9 \times 10^{-3} + .4 \times 10^{-3} + .9 \times 10^{-3}$$

$$I_T = 2.2 \times 10^{-3}$$

$$I_T = 2.2 \text{ mA}$$

3. Measure the current through R_1 , R_2 and R_3 by removing jumper wire B, C and D one at a time and installing the multimeter in place of the removed jumper wire. Record your measurements below.

I_{R_1} _____ mA

I_{R_2} _____ mA

I_{R_3} _____ mA

The current in the circuit is entering the junction formed by the lower connector and leaving the junction by three different paths. These paths are through jumper B and R_1 , jumper C and R_2 and jumper D and R_3 . The sum of the currents leaving the junction should be equal to the current entering. Add the values found in Step 3 and compare the results with the total current measured in Step 2.

CONCLUSION

In Part II we have seen that the current entering a junction point is equal to the sum of the currents leaving that junction.

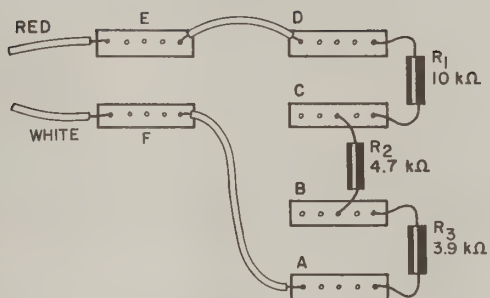


FIGURE 7-1

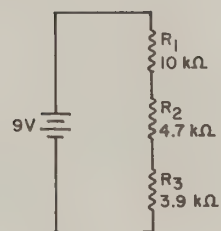


FIGURE 7-2

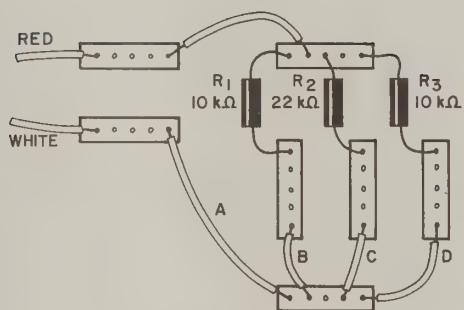


FIGURE 7-3



FIGURE 7-4

NOTES

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

9500-7A

1. If the resistance of a series circuit is increased, what happens to the current?
 A ☐ (A) Increases. (B) Decreases. (C) Remains the same.
 B ☐
 C ☐
 D ☐
2. If the resistance in a series circuit is increased, what happens to the voltage applied to the circuit?
 A ☐
 B ☐ (A) Increases. (B) Decreases. (C) Remains the same.
 C ☐
 D ☐
3. In the circuit of Figure 7-2 if the resistance values are 22 k Ω , 100 k Ω , and 47 k Ω what is the total resistance?
 A ☐
 B ☐ (A) 169 k Ω . (B) 79 k Ω . (C) 75 k Ω . (D) 18 k Ω .
 C ☐
 D ☐
4. If the current entering a junction consists of three currents of 1 mA, 10 mA and 6 mA, what is the total current leaving the junction?
 A ☐
 B ☐ (A) 6 mA. (B) 5 mA. (C) 17 mA. (D) 10 mA.
 C ☐
 D ☐
5. In a parallel circuit, if a branch is removed, what will happen to the total current?
 A ☐ (A) Increase. (B) Decrease. (C) Remain the same.
 B ☐
 C ☐
 D ☐
6.
 A ☐
 B ☐
 C ☐
 D ☐
7. (THIS EXAM CONTAINS ONLY FIVE QUESTIONS)
 A ☐
 B ☐
 C ☐
 D ☐
8.
 A ☐
 B ☐
 C ☐
 D ☐
9.
 A ☐
 B ☐
 C ☐
 D ☐
10.
 A ☐
 B ☐
 C ☐
 D ☐

EXPERIMENT 8

DC CIRCUIT ANALYSIS

PARTS NEEDED

- | | |
|---|---------------------------------------|
| 1 - Basic Design Console with 2
Modular Panels | 3 - Alligator Clips |
| 1 - 1 k Ω , 1/2 W, 20% Resistor | 1 - 9 Volt Battery with Clip |
| 1 - 4.7 k Ω , 1/2 W, 20% Resistor | Modular Connectors and Hookup
Wire |
| 2 - 10 k Ω , 1/2 W, 20% Resistors | 1 - Multimeter and Test Leads |
| 1 - 1 M Ω , Potentiometer | 2 - Test Prod Spring Adapters |

OBJECTIVE

The purpose of the following experiment is to demonstrate the action of a potentiometer, the analysis of open circuit concepts and the investigation of combination circuits.

PART 1

PROCEDURE

ASSEMBLY OF WIRE LEADS ONTO ALLIGATOR CLIPS

1. Three leads, each 7 1/2" long, are to be used with the alligator clips. One end of each lead is stripped 5/8" from the end while the other is stripped 1/2" from the end.
2. The ends of the leads that are stripped back 5/8" are inserted into the alligator clips as shown in Figure 8-1A. It will probably be necessary to put a gentle curve into the stripped end of the wire so that the end of the wire can be shoved through the hole in the bottom of the clip.
3. If the hole in the bottom of the clip will not admit the base end of the wire, it will be necessary to use a very small screwdriver, scribing tool, or tool such as an ice pick to make the hole larger. Figure 8-1B shows how to enlarge the hole.
4. When the base end of the wire is pulled all of the way through the hole, turn the screw on the clip counterclockwise so that the base end of the wire can be wrapped around the shank of the screw. Figure 8-1C shows the lead end secured when the screw is tightened.

PART 2

PROCEDURE

1. Set up the circuit shown in Figure 8-2. The schematic is shown in Figure 8-3. Do not allow the alligator clips to come in contact with each other.
2. Measure the voltage between points B and C while varying the shaft on the potentiometer. The voltage should vary from zero volts to the voltage of the battery.
3. Measure the voltage between points A and C while rotating the shaft of the potentiometer. In this case the voltage should be constant and equal to the battery voltage.
4. Measure the current in the circuit by replacing the jumper between the two upper connectors with the multimeter. Turn the shaft of the potentiometer. The current should be constant.

CONCLUSION

The current in the circuit is constant since the resistance presented to the battery is constant. The voltage between the slider (point B) and one end will vary as the shaft is tuned. The potentiometer then can be used to vary voltage from zero to the maximum voltage in the circuit.

PART 3

PROCEDURE

1. Set up the circuit shown in Figure 8-4.
2. While monitoring the voltage across R_2 , remove the resistor (R_2) from the circuit. Record the voltage measured below.

_____ volts

3. Leaving the circuit open, measure the voltage across R_1 . Record your measurement below.

_____ volts

With the circuit open, there is no current in the circuit. The voltage across the opening is equal to the source voltage. Since all of the voltage in the circuit is across the opening, the voltage across R_1 must be zero, to satisfy Kirchhoff's Voltage Law. Another way to verify the fact that E_{R_1} is zero is to use Ohm's

DC Circuit Analysis

Law. If the circuit current is zero, E_{R_1} would be found as follows:

$$E_{R_1} = IR$$

$$E_{R_1} = (0)(1 \times 10^3)$$

$$E_{R_1} = 0 \text{ volts.}$$

CONCLUSION

If a series circuit is open, the source voltage will appear across the opening, and the circuit current will be zero.

PART 4

PROCEDURE

1. Set up the circuit shown in Figure 8-5. Lay the circuit out so that you can easily measure total current, the current through R_2 and the current through R_3 .
2. Tracing current through the circuit, you will notice there is a path from the negative terminal of the battery, through R_2 , R_1 and back to the positive terminal of the battery. There is another path from the negative terminal of the battery, through R_3 , R_1 and back to the positive terminal of the battery. Since the current flowing through R_2 and the current flowing through R_3 also flows through R_1 , this resistor carries total current and is in series with the combination of R_2 and R_3 .
3. Calculate the total current in the circuit using the measured source voltage and the rated resistance values. Measure the total current and record both the calculated and measured values below.

I_T _____ mA, calculated

I_T _____ mA, measured

Your calculations should be similar to those below where the rated values of the parts are used. Remember, different procedures can be followed to obtain the same answer. The method of solution is not important as long as the correct answer is obtained.

This is one set of calculations for determining the equivalent resistance of R_2 and R_3 in parallel and the total resistance and current:

$$R_{eq} = \frac{R_2 R_3}{R_2 + R_3} = \frac{(10 \times 10^3)(10 \times 10^3)}{10 \times 10^3 + 10 \times 10^3} = \frac{100 \times 10^6}{20 \times 10^3} = 5 \times 10^3 = 5 \text{ k}\Omega$$

$$R_T = R_1 + R_{eq} = 4.7 \text{ k}\Omega + 5 \text{ k}\Omega = 9.7 \text{ k}\Omega$$

$$I_T = \frac{E_T}{R_T} = \frac{9 \text{ V}}{9.7 \times 10^3} = .9 \text{ mA (approx.)}$$

4. Using your measured value for I_T , calculate the voltage across R_1 . Measure the voltage and record both values below.

E_{R_1} _____ volts, calculated

E_{R_1} _____ volts, measured

Your calculations should be similar to those below:

$$E_{R_1} = I_T \cdot R_1 = (.9 \text{ mA})(4.7 \text{ k}\Omega) = (.9 \times 10^{-3})(4.7 \times 10^3) = 4.23 \text{ volts.}$$

5. Using Kirchhoff's Voltage Law, determine the voltage across the combination of $R_2 + R_3$. Use the measured voltage in your calculations. Measure the voltage and record both values below.

$E_{R_2+R_3}$ _____ volts, calculated

$E_{R_2+R_3}$ _____ volts, measured

Your calculations should be similar to those below:

$$E_{R_2+R_3} = E_T - E_{R_1} = 9 \text{ V} - 4.23 \text{ V} = 4.77 \text{ volts.}$$

6. Using the voltage measured in Step 5 and the rated value of R_2 and R_3 , calculate the current through each resistor. Measure the current through R_2 and R_3 and record all values below.

DC Circuit Analysis

I_{R2} _____ mA, calculated

I_{R3} _____ mA, calculated

I_{R2} _____ mA, measured

I_{R3} _____ mA, measured

The calculations using rated values are below:

$$I_{R2} = \frac{E_{R2}}{R_2}$$

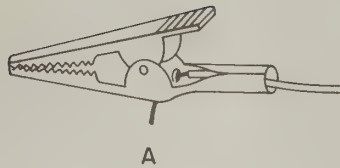
$$I_{R2} = \frac{4.77 \text{ volts}}{10 \times 10^3 \Omega} = .477 \times 10^{-3} \text{ A} = .477 \text{ mA}$$

$$I_{R3} = \frac{4.77 \text{ volts}}{10 \times 10^3 \Omega} = .477 \text{ mA.}$$

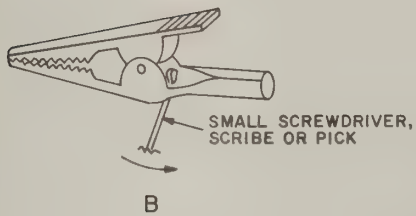
CONCLUSION

Circuits such as the one shown in Figure 8-5 cannot be analyzed using only laws of series circuits or only laws of parallel circuits. Combination circuits must first be reduced to simpler circuits. Usually eliminating any parallel branches by calculating the equivalent circuit is the first step.

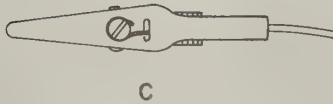
NOTES



A



B



C

FIGURE 8-1

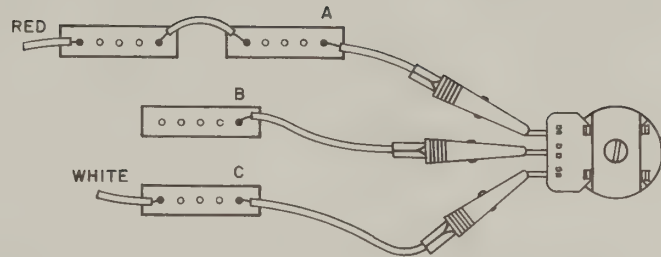


FIGURE 8-2

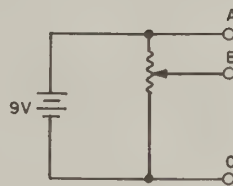


FIGURE 8-3

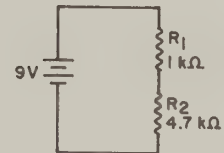


FIGURE 8-4

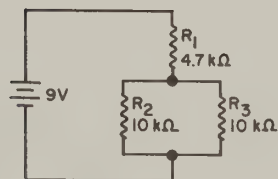


FIGURE 8-5

NOTES

QUESTIONS

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LESSON CODE

9500-8A

1. A series circuit consists of a 10 k Ω resistor and a 5 k Ω resistor. What is the voltage across the 5 k Ω resistor if the circuit is open (5 k Ω resistor is good) and the source voltage is 15 volts?
 (A) 5 volts. (B) 15 volts. (C) 0 volts. (D) 10 volts.

☐ A

☐ B

☐ C

☐ D
2. A potentiometer can be used to vary the voltage in a circuit.
 (A) True. (B) False.

☐ A

☐ B

☐ C

☐ D
3. If the source voltage in Figure 8-3 is increased to 18 volts and the potentiometer setting is not changed, the voltage from point B to point C will
 (A) increase. (B) decrease. (C) remain the same.

☐ A

☐ B

☐ C

☐ D
4. The circuit shown in Figure 8-5 is
 (A) a series circuit. (B) a parallel circuit. (C) neither a series nor a parallel circuit.

☐ A

☐ B

☐ C

☐ D
5. In Figure 8-5 change R₁ to 10 k Ω , R₂ to 20 k Ω and R₃ to 20 k Ω . What is the voltage across R₁?
 (A) 4.5 V. (B) 3 volts. (C) 10 volts. (D) 6 volts.

☐ A

☐ B

☐ C

☐ D
6.

☐ A

☐ B

☐ C

☐ D
7.

☐ A

☐ B

☐ C

☐ D
8.

☐ A

☐ B

☐ C

☐ D
9.

☐ A

☐ B

☐ C

☐ D
10.

☐ A

☐ B

☐ C

☐ D

(THIS EXAM CONTAINS ONLY FIVE QUESTIONS)

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